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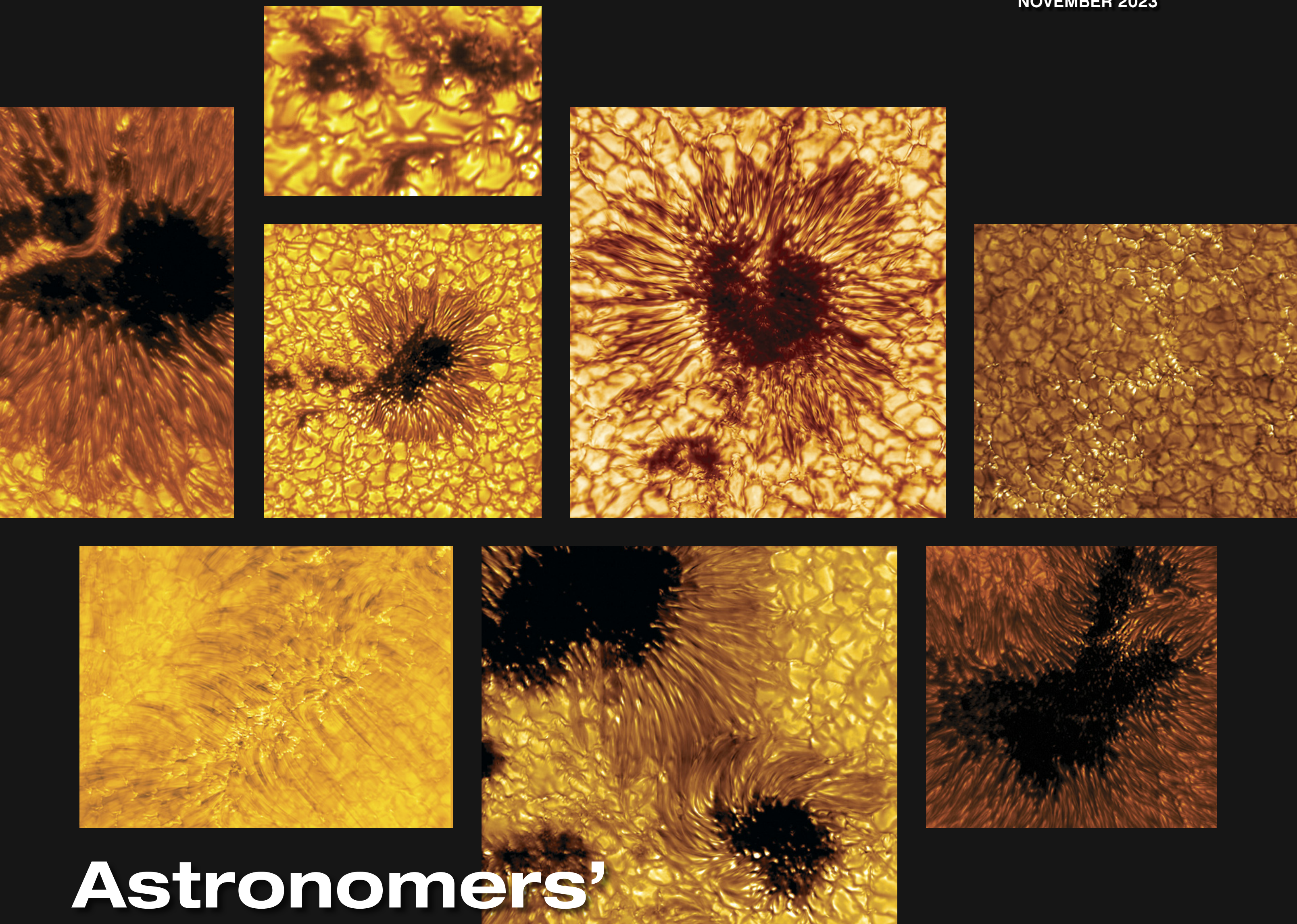
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

NOVEMBER 2023



Astronomers' New Eye on the Sun

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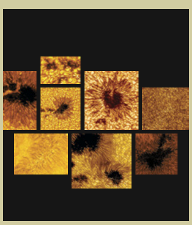
ON THE COVER



DKIST images of active and quiet regions on the Sun

PHOTOS: NSO / AURA / NSF

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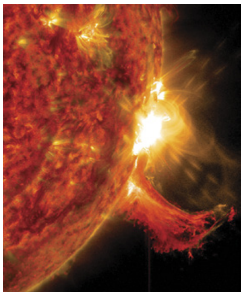
Outer Limits

IMAGINE LOOKING AT a free-floating ball of gas. What would you see? Even if the gas had some color or texture to it, you might be hard-pressed to tell where the surface of the ball begins and ends, where exterior gives way to interior.

That's exactly our experience when observing the Sun (safely, of course). Stars throw the whole concept of surface out of whack. A soap bubble has more of a defined shell than our star does. Indeed, when we observe the Sun, we're not so much looking *at* it as *into* it, albeit not very far.

Fortunately, while the Sun doesn't have a solid surface, it does have a visible one, the *photosphere*. Serving as the base of the solar atmosphere, the photosphere gives itself away — and aids us in delimiting the "surface" — by hosting a range of distinctive phenomena. (See the stunning images on the cover and in the corresponding feature on page 14.)

Among these phenomena are *sunspots*, those dark regions that resemble misshapen sunflowers. A sunspot's black center, its *umbra*, and the wispy *penumbra* that envelops it lend a sense of a horizontal layer to what is otherwise ever-roiling plasma. Sunspot umbrae are darker than their surroundings because they're comparatively cooler: around 3700°C (6700°F) rather than the predominant 5500°C (9900°F).



▲ A solar flare erupts from the photosphere in this image taken by NASA's Solar Dynamics Observatory.

NASA / SDO

Outside of sunspots, most of the photosphere consists of *granules*, which the Daniel K. Inouye Solar Telescope, the subject of our cover story, captures better than any telescope before it (see the dramatic image on page 15). Looking like plasma popcorn, granules sheath the Sun's entire visible surface, the "popped kernels" each thousands of kilometers across.

The edge, or limb, of the Sun provides an alternate sense of a covering, an impression enhanced by *limb darkening*: When we look near the rim, we aren't peering as deeply into the Sun as when we look at the middle. As such, we see only the slightly cooler outer layers of plasma, which in turn appear slightly darker.

Other, loftier solar features also enhance our inkling of a surface from which they arose. These include *prominences*, those dazzling flares of plasma that extend from the photosphere right up to the corona.

Altogether, the solar spectacles transpiring in and above the photosphere help us visually grasp the giant ball of gas that is our Sun. Without them, we'd have a much harder time wrapping our heads around what essentially doesn't have a wrapping.

Peter

Editor in Chief

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The Essential Guide to Astronomy

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Subscription Rates:
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Canada: $73.18 (including GST)
All other countries: $88.63, by expedited delivery
All prices are in U.S. dollars.

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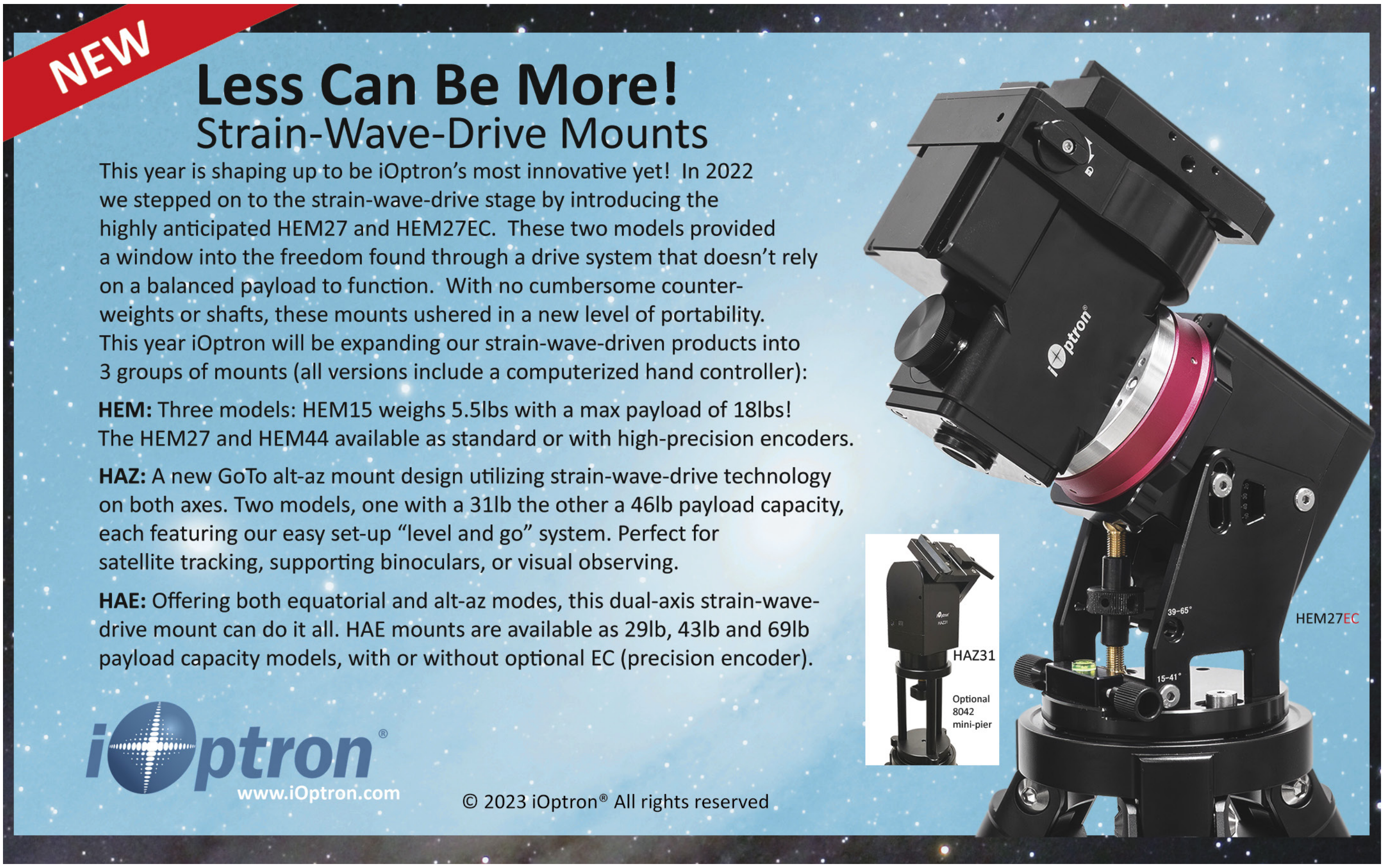
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Less Can Be More!
Strain-Wave-Drive Mounts
This year is shaping up to be iOptron's most innovative yet! In 2022 we stepped on to the strain-wave-drive stage by introducing the highly anticipated HEM27 and HEM27EC. These two models provided a window into the freedom found through a drive system that doesn't rely on a balanced payload to function. With no cumbersome counter-weights or shafts, these mounts ushered in a new level of portability. This year iOptron will be expanding our strain-wave-driven products into 3 groups of mounts (all versions include a computerized hand controller):
HEM: Three models: HEM15 weighs 5.5lbs with a max payload of 18lbs! The HEM27 and HEM44 available as standard or with high-precision encoders.
HAZ: A new GoTo alt-az mount design utilizing strain-wave-drive technology on both axes. Two models, one with a 31lb the other a 46lb payload capacity, each featuring our easy set-up "level and go" system. Perfect for satellite tracking, supporting binoculars, or visual observing.
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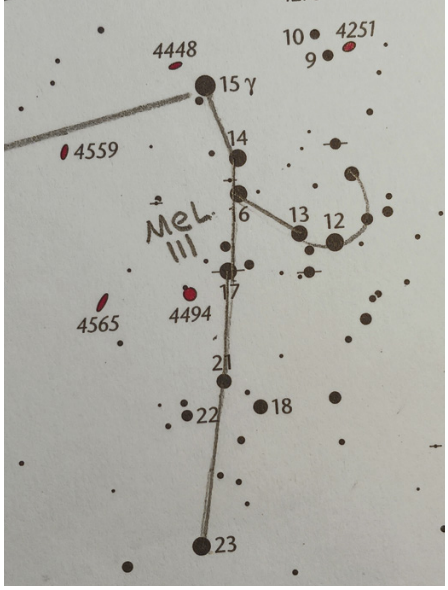
Hanging by a Hair

I really enjoyed Ken Hewitt-White's "A Cosmic Coathanger Caper" (*S&T:* July 2023, p. 54). I always look forward to his articles, which combine his adroit observational skills with a dash of humor. And it was nice to see a comprehensive piece on this unique asterism.

I wonder if I'm the only stargazer on the planet who sees another, larger hanger in the heavens these July evenings? I refer to Mel 111, the open star cluster in Coma Berenices above the hindquarters of Leo, the Lion. As lovely as it is, for many years, I only saw a shotgun blast of stars. But recently, perhaps due to light pollution, which dims some of its fainter members, I see a hanger amongst its stars.

There are several differences, however. This hanger is over three times as large as Cr 399 (Mel 111 fills my 8° binocular field), it runs north to south rather than east-west, and the hanger part is not as straight as Cr 399's is. Perhaps this is an example of pareidolia, the reason I always see the Lady in the Moon when I look at a full Moon.



Bill Dellinges
Apache Junction, Arizona

Keeping an Eye on the Sky

In reference to Scott Harrington's "Far-Out Globular Clusters" (*S&T:* June 2023, p. 20), I would like to raise an intriguing question for amateurs: Which deep-sky objects look the most beautiful visually?

Amateur astronomers can now easily take photographs of galaxies with stunning beauty, and usually these photographs look better than anyone can achieve visually even with a very large telescope. But when comparing views of globulars like M13 or NGC 5139, I have noted that their photos lack a lot of the grand effect as seen through an eyepiece of a good telescope with decent aperture. Some tiny, delicate structure of the blue giants over the background of unresolved stars is missing in photographs.

This suggests a more general question: What are the other advantages (if any) of observing over astrophotography?

Zbigniew Zembaty
Opole, Poland

Quasimoto Moon

Perhaps the latest quasi-moon (**https://is.gd/newquasimoon**) should be named "Quasimoto?" 😜

I have always thought that NASA should send long-term instrument packages to such closely passing quasi-moons, or even long-term-solar-orbiting objects, so that they hitch a ride on them. Say a telescope, for example? I would think that they could do very useful science.

Lewis Brackett
San Diego, California

Unidentified Anomalous Phenomena

It's good to see the NASA panel on Unidentified Anomalous Phenomena (UAPs), **https://is.gd/UAP_Panel**, clearly and carefully evaluate the fragmentary (and often rushed) observations that constitute most UAP reports.

I hope they will hear not only from scientists and military personnel, but also from skeptical investigators who have spent a great deal of time already investigating and successfully debunking the "alien spaceship" hypothesis for many of the best-known sightings. Mick West is an excellent example of such careful investigators. I have put together a resource guide to some of the skeptical literature available on the internet, and you can see it at: **http://bit.ly/ufoskeptic**.

Andrew Fraknoi
Fromm Institute
University of San Francisco
San Francisco, California

Astronomy for the Ages

Thank you for publishing Emily Lakdawalla's excellent article "Sights Set on Uranus" (*S&T:* July 2023, p. 14). Late in the article, she makes the point that the mid- to late-career scientists who are proposing missions to Uranus right now will not be the ones who get to analyze the results from these missions. Instead, by the time such a mission has reached Uranus, it will belong to today's early-career scientists.

That will be even more true of future interstellar missions. Even moving at 5% of the speed of light, which is far beyond today's technology, a probe would take more than 80 years to reach the nearest star and send data back. Only the grandchildren of those who launch interstellar probes will see the results.

John Sauter
Nashua, New Hampshire

Camille M. Carlisle replies: *You're right that interstellar missions will require even more patience. The Breakthrough Starshot initiative (***https://is.gd/Breakthrough_***) is exploring the design of tiny, solar-sail spacecraft that could be accelerated to 20% of the speed of light, reaching the Alpha Centauri system in about 20 years. There's been research on that front in the past few years, exploring sail designs and such (***https://is.gd/TravelTime***). But it's unclear when, or whether, such a mission will come to fruition.*

A Future from the Past

Roger W. Sinnott's August 75, 50 & 25 Years Ago column (*S&T:* Aug. 2023, p. 7) quoted the August 1998 article "The Future of the Universe" by Fred C. Adams and Gregory Laughlin (*S&T:* Aug. 1998, p. 32). That was a memorable article to me, and I have to wonder if current understanding of cosmic evolution would change the conclu-

ASTERISM LINES: BILL DELLINGES; STAR CHART: *SKY ATLAS 2000.0* / ROGER W. SINNOTT AND WILL TIRION

sions of that article. For instance, there was no mention in the article of dark energy. Would that have any appreciable effect 10^{100} years in the future?

Tom Killgore
Collinsville, Oklahoma

Roger W. Sinnott replies: *You've put your finger on what is probably the most significant discovery since Adams and Laughlin wrote their article: dark energy. Coincidentally, the observations that led to a 2011 Nobel Prize for Perlmutter, Riess, and Schmidt were made the same year — 1998 — as the article was published. The authors even seem to acknowledge those observations when they note that then-recent work, "bolstered by new studies announced early this year, lean strongly toward [Omega-naught] being as low as 0.2 or 0.3" (that is, implying the universe will continue to fly apart forever, although not in the exact manner dark energy predicts).*

Of course, the authors filled their article with caveats and warnings that many of their statements were tentative and sure to be revised. Even an event due to happen as soon as five billion years from now, the swelling of our Sun into a red giant, has uncertain consequences. Adams-Laughlin thought the Earth would escape being swallowed up, but a quite recent article in the New York Times *paints a rather different picture:* **https://is.gd/PlanetEater**.

Conifer Confusion

The cover of the June 2023 issue perpetuates a common misunderstanding. The park service at Bryce Canyon National Park promotes the fact that bristlecone pine trees are among the longest-living trees in the world. This naturally leads people to want to see one, which in turn causes them to misidentify most pine trees on the rim as bristlecone pines. Bristlecone pines have short (1-inch-long) needles in clumps of five with a bottle-brush appearance all along the branch. The tree on the June cover is probably a small ponderosa pine, the most common tree on the rim, characterized by long needles (4 to 8 inches long) in tufts on the ends of the branches. I know you aren't a botany magazine. I'm just trying to do my small part to correct a common misconception.

Rod Parker
Salt Lake City, Utah

◀ The tree to the left is a bristlecone pine. The one to the right is a ponderosa pine like the one on the cover of the June issue.

ROD PARKER

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75, 50 & 25 YEARS AGO by Roger W. Sinnott

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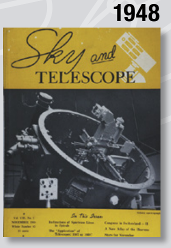
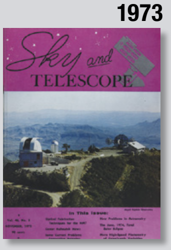


1973



1998

◖ November 1948

Turning How? "V. M. Slipher placed the slit of a spectrograph on a spiral nebula and obtained a spectrogram that showed inclined lines. From this result he concluded that the spiral was rotating about an axis — that on one side of its center the material of the galaxy was approaching us relative to the center and on the other side receding. [His work] opened a new field of investigation: [galaxy] dynamics . . .

"The field, however, has proven difficult to cultivate, [and] the interpretation of spectrum-line inclinations as rotations is fraught with many difficulties; . . . it has been done only for . . . M31 and M33."

Many years would pass before astronomers knew that most spirals rotate to "wind up" their arms. Rarely, some arms are unwinding.

◖ November 1973

Nailing It "One of the most venerable and fundamental areas of research, the astronomy of precision stellar positions and proper motions, is on the move. During the week of August 12, 1973, an astrometry symposium was held in Perth, Western Australia, [concerning] new approaches developed during the past five years or so. The most spectacular of these is *radio astrometry*, which burst full-grown upon the scene!

"Why have a symposium on star positions? Do we not know the right ascensions and declinations of the stars with sufficient precision already? The answer is definitely *no* [owing] to our constantly changing sky. . . . Hence, emphasis must be given to getting precise optical positions for radio sources that have been identified optically."

Bart Bok's enthusiasm was justified. Today, positions of exceedingly remote sources like quasars, gauged by long-baseline radio interferometry, define the unchanging reference frame for all else in astronomy.

◖ November 1998

Spectral Types "Move over, *M* stars! There's a new kid on the dim, red end of the block. A group of astronomers has declared a new spectral class, *L*, to follow the *O, B, A, F, G, K,* and *M* that generations of astronomy students have committed to memory. J. Davy Kirkpatrick (Caltech) and his colleagues made their discovery by sifting through data from the Two-Micron All-Sky Survey (2MASS) . . .

"[Among] 20 of their targets . . . 'rusty' molecules like titanium oxide (TiO) and vanadium oxide (VO) become scarce, even though those compounds are prominent in the slightly hotter late-type *M* dwarfs. . . . Another feature sets *L* dwarfs apart from their precursors: they are largely if not wholly made up of brown dwarfs, not-quite-stars that can't sustain hydrogen-fusion reactions."

Since then, types T and Y have been added for brown dwarfs even cooler than L.

◀ Artist's impression of a satellite constellation in orbit above the LOFAR telescope

MEGACONSTELLATIONS

Satellites Leak Radio Emission

RADIATION LEAKING from Earth-orbiting satellites, now detected for the first time, may become a major problem for radio astronomy as the number of satellites continues to grow.

Satellites' communication signals are strong but are by regulation limited to certain wavelengths, and they can be filtered out. However, satellites may also leak artificial signals at unintended wavelengths, and this radiation isn't regulated to the same degree. A team led by Federico Di Vruno (Square Kilometre Array Observatory) has announced the first detection of this electromagnetic interference from satellites in large constellations.

Di Vruno and colleagues used the core antennas of the Low-Frequency Array (LOFAR) in the Netherlands to look for signals from satellites in SpaceX's Starlink constellation, which at the time numbered 2,100 (currently, there are more than 4,000). Out of 68 observed satellites, 47 were detected at frequencies between 110 and 188 MHz, well below the 10.7 to 12.7 GHz radio frequencies reserved for downlink communications. The report will appear in *Astronomy & Astrophysics*.

"Every electric device generates leakage radiation," explains team member Gyula Józsa (Max Planck Institute for Radio Astronomy, Germany). But as the number of satellites increases, so will the radiation they leak.

"Usually, we just eliminate data that has been contaminated by a satellite from further processing," Józsa says. "The more this happens, the more observation time we lose." Even more troubling, weak artificial signals may hide in the noise, which could lead to erroneous results when typical methods for noise reduction are employed.

So far, the researchers have only obtained one-hour "snapshot" observations. They plan to follow up to better understand how much radiation leaks from Starlink and other satellites.

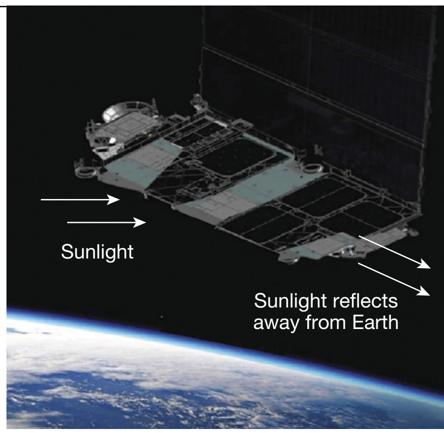
■ JAN HATTENBACH

MEGACONSTELLATIONS

New, Larger Starlink Satellites Are Faint

SPACEX LAUNCHED the first batch of second-generation Starlink satellites dubbed "Minis" on February 27th. They are only small in comparison to the full-size version that will come later: With 116 square meters of surface area, Minis are more than four times the size of the satellites in the previous generation. SpaceX has since launched several additional batches.

While the Minis' large dimensions were an immediate concern to astronomers, SpaceX also changed the physical design and concept of operations in order to mitigate their brightness. The company applied a highly reflective dielectric mirror film to several parts of the spacecraft body, in order to reflect sunlight into space rather than scatter it toward observers on the ground.



▲ Dielectric mirror surfaces on the spacecraft body reflect sunlight (coming from the left), directing it into space rather than down to the ground. Special black paint is put on some areas where the dielectric film can't be applied.

On some areas that couldn't take the dielectric layer, the company used low-reflectivity black paint. In addition, the solar panels can be oriented so that observers do not see their sunlit sides.

To check the brightness mitigation plan, a group of seven satellite observers (including the author) began recording magnitudes both visually and with a camera, prioritizing measurements for spacecraft that SpaceX confirmed were operational. Our group found that these had an average magnitude of 7.1. These satellites are thus slightly fainter than astronomers' guidelines and are invisible to the unaided eye.

Next, we adjusted the observed magnitudes to a uniform distance of 1,000 km from the observer, in order to compare the intrinsic magnitudes of mitigated and unmitigated spacecraft: 7.9 and 5.1, respectively. The new satellites are on average dimmer by a factor of 12, as reported in a paper posted on the arXiv astronomy preprint server. But our work isn't done yet: We need more Starlink magnitudes to characterize and monitor the brightness of the new and upcoming satellites.

■ ANTHONY MALLAMA

ARTIST'S CONCEPT OF SATELLITES ABOVE A RADIO ARRAY: DANIËLLE FUTSELAAR; ILLUSTRATION OF DIELECTRIC MIRRORS ON STARLINK SATELLITE BODY: SPACEX

RADIO ASTRONOMY

Astronomers Find Mysterious, Slowly Pulsing Star

AN UNIDENTIFIED SOURCE was discovered beaming brief radio-wave pulses every 22 minutes, and it has been going for decades, Natasha Hurley-Walker (Curtin University, Australia) and colleagues report in the July 20th *Nature*. The team found the source using the Murchison Widefield Array (MWA) in Western Australia. The team carried out follow-up observations with the MWA as well as with other radio observatories in Australia and South Africa. Archival data from the Very Large Array in New Mexico and India's Giant Metrewave Radio Telescope show the source's signal has been stable since 1988.

The lethargic blinker, known as GPM J1839–10, doesn't act like a regular *pulsar*. These neutron stars emit particles and radiation along their magnetic poles, creating beams that sweep by Earth with periods of milliseconds to seconds long. Strongly magnetized neutron stars, known as *magnetars*, can have periods on the order of minutes, but more slowly spinning neutron stars aren't expected to produce lighthouse-like beams.

Instead, the team proposes that they've found a highly magnetic white dwarf. Because a white dwarf is larger than a neutron star and its mass is more spread out, it could power a bright beam even if it has a relatively slow rotation rate. However, no isolated white dwarf has ever shown such bright radio emission, let alone via pulses.

Victoria Kaspi (McGill University, Canada), who wrote an accompanying perspective in the same issue of *Nature*, isn't ready to give up on a pulsar explanation for GPM J1839–10. "Nature can be more inventive than astrophysical theorists," she says. "The physics of radio pulsar magnetospheres is very rich and there is room for modifications.

"Still," she adds, "I like the white dwarf model, mainly because it is testable." Indeed, very sensitive observations at visible and infrared wavelengths might reveal a counterpart.

■ GOVERT SCHILLING

IN BRIEF

Little to No Air on TRAPPIST-1c

Observations from the James Webb Space Telescope (JWST) have already shown that the innermost world of the seven-planet TRAPPIST system is airless (*S&T:* Aug. 2023, p. 8). Now, data published June 19th in *Nature* suggest the next world out, TRAPPIST-1c, could at best host a thin carbon-dioxide atmosphere — but it's also possible that c is just as bare as b. The team, led by Sebastian Zieba (Max Planck Institute for Astronomy, Germany), used JWST's mid-infrared camera to watch TRAPPIST-1c pass behind its star and captured its dayside brightness at 15 microns, a wavelength that carbon dioxide molecules absorb. Based on that data, the team calculated a daytime temperature of 380K (224°F), which suggests that if the planet has a carbon-dioxide-based atmosphere at all, it's even thinner than the one on Mars. Upcoming observations will probe the viability of atmospheres on the system's rocky outer worlds.

■ MONICA YOUNG

Read the full story at https://is.gd/TRAPPIST1c.

EXTRASOLAR SYSTEMS

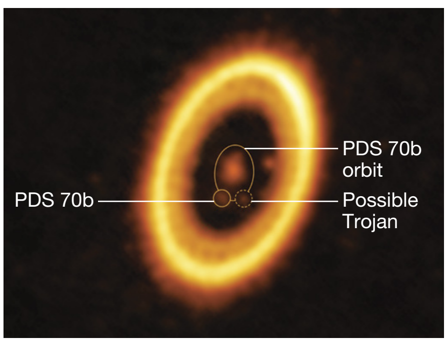
One Orbit, Two Planets?

CAN TWO WORLDS occupy the same orbit? Gravitationally stable regions lead and trail a planet in its orbit, so it's possible that alongside a gas giant, a second world (or a collection of bodies) with up to a super-Earth's mass could form. But we haven't seen anything quite like that — yet.

In the July *Astronomy & Astrophysics*, Olga Balsalobre-Ruza (Center of Astrobiology, Spain) and colleagues report the discovery of a clump of dust in just such a stable region, trailing at the L_5 Lagrange point behind the already discovered newborn planet PDS 70b.

"I was not expecting that we could detect Trojan bodies," says exoplanet expert Sebastiaan Haffert (University of Arizona), who was not involved in the study. "The authors of this work make a very compelling case."

PDS 70b is an infant gas giant about 370 light-years away from Earth and 22 astronomical units (a.u.) from its 5 million-year-old host star. The planet is shrouded in dust, which glows brightly for the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile. Applying new processing techniques to publicly available ALMA images, Balsalobre-Ruza and her team found that a second glob of warm dust might be following PDS 70b around its star.



▲ This image shows a glob of dust alongside protoplanet PDS 70b. The glob might be dust enshrouding a Trojan world or worlds.

ALMA (ESO / NAOJ / NRAO) / BALSALOBRE-RUZA ET AL. / *ASTRONOMY & ASTROPHYSICS* 2023

That clump's glow indicates that it holds less than two Moons' worth of dust. But it may have more than that, Balsalobre-Ruza points out. "The ALMA data we have used for this detection is only sensitive to dust particles with sizes of 2 millimeters," she explains. "More particles of different sizes are expected to be in the region."

This clump of dust has the potential to form or enshroud a planet, she notes. However, Haffert adds that we might instead be seeing the formation of a smaller body, like the largest asteroids in the main belt of the solar system. Future infrared observations could detect emission directly from the forming object(s), Balsalobre-Ruza says. Meanwhile, February 2026 will offer the first opportunity to confirm that the dusty mass shares PDS 70b's orbit.

■ MONICA YOUNG

COSMOLOGY

Dust at Cosmic Dawn

DESIGNED TO FIND and characterize early galaxies, the James Webb Space Telescope (JWST) has revealed another mystery. An international team led by Joris Witstok (University of Cambridge, UK) has used JWST to investigate the dust in a number of galaxies from the first few hundred million years after the Big Bang. The results of their study, published July 19th in *Nature*, could pose problems for some ideas about stellar evolution and dust formation.

Witstok's team used JWST to look at 253 early galaxies. A near-infrared spectrum that combines the light from 10 of these galaxies revealed evidence for a familiar spectral feature associated with carbon-rich dust, known as *polycyclic aromatic hydrocarbons* (PAHs).

Beyond our galactic neighborhood, this feature is typically only observed in massive galaxies that have been enriched by many generations of star formation. Astronomers think PAH dust grains form in the winds of dying *asymptotic giant branch* (AGB) stars. And since it takes more than 1 billion years for a star to evolve into the AGB phase, astronomers were not expecting to see evidence of PAHs in the early universe. "Something is making this dust very quickly," Witstok concludes.

In the study, the team suggests that the dust might form within material ejected by supernovae, or in the strong winds from rare, massive Wolf-Rayet stars, but the exact mechanisms are still unknown. "This is going to open up a whole new debate in this field," says Tayyaba Zafar (Macquarie University, Australia), who was not involved in this study. "People will be rethinking which type of stars can produce sufficient dust to match these observations."

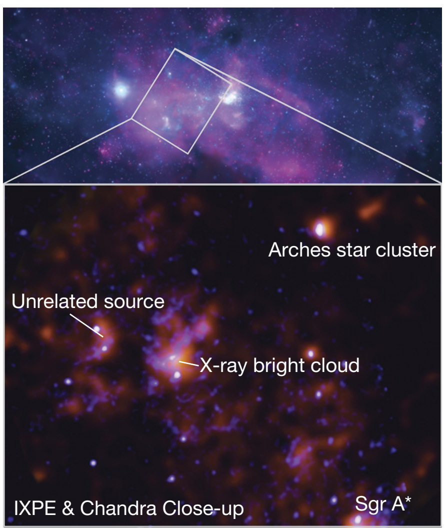
■ ARWEN RIMMER

BLACK HOLES

The Milky Way's Black Hole Flared 200 Years Ago

THE MILKY WAY'S supermassive black hole, also known as Sagittarius A* (Sgr A*), is faint and quiet. But it hasn't always been that way. According to research in the July 6th *Nature*, Sgr A* flared as recently as two centuries ago.

In the 1990s, X-ray images of our galaxy's center revealed that, while Sgr A* was dim, clouds of gas and dust around it were glowing brightly. Since such *molecular clouds* don't usually emit X-rays, astronomers at the time proposed that the clouds were reflecting light from another, much brighter source, explains Frédéric Marin (University of Strasbourg, France), who led the new study.



▲ The inset at bottom zooms in on the galactic center (imaged by the Chandra X-ray Observatory at top). The close-up combines X-rays (blue) with X-ray polarization (orange).

According to that prediction, that reflected light should be polarized; that is, its waves should vibrate in a preferred direction. Now, astronomers are finally able to observe the polarization of the high-energy radiation with the Imaging X-ray Polarimetry Explorer (IXPE). The proposed scenario held up: Sgr A*'s X-rays aren't polarized, but those from the clouds are.

Marin and colleagues note that the polarization points to Sgr A* as the illuminating source. However, Maïca Clavel (Grenoble Alpes University, France), who wasn't involved in the study, says that the polarization data aren't decisive. Nevertheless, she's confident that Sgr A* is indeed the source astronomers have been looking for. "Based on all the observations that have been gathered since the 1990s, it's the only candidate left," Clavel says.

Based on the distance from the black hole to the clouds, the team estimates that Sgr A* fed and flared some 200 years ago. If the flare lasted less than a year or so, as found by previous studies, then Sgr A* became at least a million times brighter in X-rays than it is today. The team is planning more IXPE observations are in the works.

■ JURE JAPELJ

IN BRIEF

ESA's Euclid Launches

The European Space Agency's Euclid mission launched on July 1st, headed to orbit at the Sun-Earth L_2 Lagrange point. The telescope's visible and near-infrared detectors will capture galaxy spectra across a large field of view, enabling astronomers to measure the effects of dark energy and dark matter over cosmic time. Using a "step and stare" method, Euclid will scan a third of the sky and probe the growth of cosmic structures over the past 10 billion years (to a redshift of 2). As of press time, Euclid is undergoing commissioning before it begins its six-year primary mission.

■ DAVID DICKINSON

Read more at **https://is.gd/070123.**

India: Moon Mission #3

India is headed back to the Moon with Chandrayaan 3, consisting of an orbiter, a lander, and the Pragyan rover. The mission, which launched successfully on July 14th, follows the 2019 crash of Chandrayaan 2's Vikram lander on the lunar surface. The new lander includes several improvements to increase its chance of success. In late August, the lander will target a site on the lunar nearside, near Mutus Crater in the lunar south polar region. While a soft landing on the Moon is the mission's main objective, the lander and rover also carry multiple science instruments for exploring the surrounding terrain.

■ DAVID DICKINSON

Read more at **https://is.gd/071423.**

IXPE: NASA / MSFC / F. MARIN ET AL; CHANDRA: NASA / CXC / SAO; IMAGE PROCESSING: L. FRATTARE, J. MAJOR, AND K. ARCAND

Seeing Through the Smoke

The near-term haze of climate disasters obscures our possible futures. But long-term trends leave room for optimism.

ALEX WONG / GETTY IMAGES

▲ Hazy smoke from wildfires burning in far-off Canada grays out the Washington Monument on June 8, 2023.

THIS MAY BE MY LAST Cosmic Relief column, at least for now: I've accepted the position of Senior Scientist for Astrobiology Strategy at NASA, which sadly will eat up my writing time. Contributing to *S&T* has been a great gig, and I truly appreciate all the wonderful feedback from readers over the years.

I just re-read my first column, from January 2009 (**https://is.gd/CRfirst**). In it I describe a conversation with my father about the future, juxtaposing his pessimism, at age 80, with the hopeful perspective I gained from the SETI conference I was then attending. He felt that humans were losing the "race between education and catastrophe," as H. G. Wells warned in 1920. My dad worried about his grandkids growing up in a world harmed by climate change.

I shared his concerns, but these were counterbalanced by my enthusiasm about the imminent launch of the Kepler spacecraft, which promised to reveal the numbers and demographics of exoplanets. Kepler's results would enable us to do *comparative planetology*. By putting our solar system in context, we could learn more about how planets work and how life integrates into planetary functioning, equipping us to better manage our role on Earth.

My father lived another 12 years, long enough to savor Kepler's dramatic confirmation of our most optimistic speculation that planets are, in fact, ubiquitous in the universe. Up until his death three years ago at age 92, his foreboding was leavened by his love of the natural world, embodied in bird-watching forest walks and, as his mobility declined, in enjoying online bird-cams and Hubble and Mars-rover images.

As I write this, the skies over me in Washington, D.C. look strangely Martian, with the Sun oddly dim and red. The haze comes from wildfires burning out of control in Canada. But I don't "blame Canada" (as the South Park song goes). We are all to blame for Earth's changing atmosphere. As the look of our skies becomes more Martian, the temperatures are becoming more Venusian. Since I wrote that first column, the CO_2 in our atmosphere has risen about 10% and now hovers at 422 parts per million. Heat records are being broken at a frightening pace.

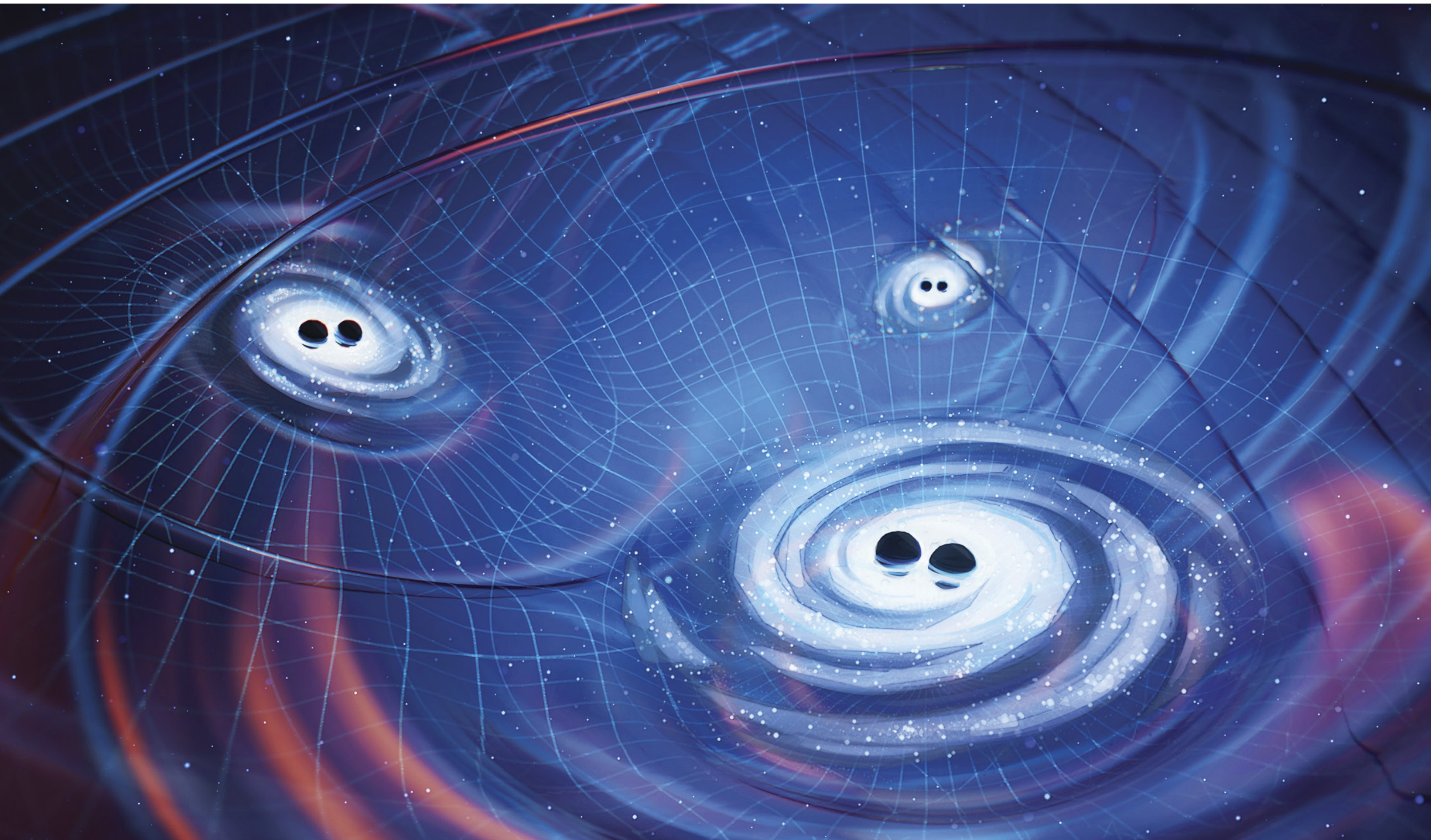
The faint silver lining to accelerating climate disasters is that the threat is no longer as abstract. Most nations can be counted on to act in their own perceived self-interest. Fearing their own climate calamities will help major powers move beyond fossil fuels.

Some trends are bending in our favor on that front. The costs of alternative energy have fallen faster than anyone predicted 10 years ago. We're starting to wean ourselves off fossil fuels — far too slowly, but we can still avoid worst-case scenarios. We've already passed peak human birth rate, and later this century population curves will start to arc downward, relieving pressure on nature. Carbon emissions, too, will likely soon peak and begin to decline.

I believe we'll muddle through this century, learning lessons the hard way but in time forging a sustainable global society in which our technological skills, perhaps aided by machine intelligence, integrate with natural systems rather than run roughshod over them.

Another Wells quote comes to mind: "Our choice is limited: either the whole universe or nothing." I still believe we'll choose the whole universe, and that eventually we'll move out to live among the stars, not in a hurried escape from a ruined Earth but as a diaspora of our descendants who've learned what it takes to live and work well within the limits and cycles of planetary systems.

■ **DAVID GRINSPOON** is author of *Earth in Human Hands: Shaping Our Planet's Future*, among other books.



Gravitational-wave Background REVEALED

Observations of more than 100 pulsars show evidence for a new type of spacetime ripple: a sea of waves from pairs of supermassive black holes.

Radio observatories across the globe have found compelling evidence for a background hum of low-frequency *gravitational waves*, the slow and minuscule undulations of spacetime thought to be produced by distant supermassive black hole pairs.

"After years of work, [we are] opening an entirely new window on the gravitational-wave universe", says Stephen Taylor (Vanderbilt University), chair of the North American Nanohertz Observatory for Gravitational Waves (NANOGRAV) collaboration.

Albert Einstein predicted gravitational waves' existence more than a century ago, but only in 2015 did the Laser Interferometer Gravitational-wave Observatory (LIGO) first detect them. Ever since, U.S. LIGO scientists and their international collaborators have found dozens of short bursts produced by the collisions of stellar-mass black holes or neutron stars (*S&T:* June 2022, p. 12). These signals have high frequencies up to a few thousand hertz, or ripples per second.

However, the universe is also expected to bathe in a sea of continuous, low-frequency gravitational waves, with spacetime slightly expanding and contracting only once every couple of decades or so. As reported by multiple groups on June 28th in the *Astrophysical Journal Letters*, *Astronomy*

▲ **GRAVITATIONAL SYMPHONY** Supermassive black hole binaries at the cores of galaxies create a background hum of spacetime ripples that suffuses the universe.

OLENA SHMAHALO / NANOGRAV

& Astrophysics, *Publications of the Astronomical Society of Australia*, and *Research in Astronomy and Astrophysics*, this long-sought background signal is now finally emerging in high-precision radio observations.

"It's as if LIGO can only hear the high pitch of a piccolo, while we listen to the low vibrations of a contrabass," explains Gemma Janssen (ASTRON Netherlands Institute for Radio Astronomy). "To understand the whole symphony, you obviously need both."

The studies employ pulsars across the Milky Way as their detector. As low-frequency gravitational waves stretch and squeeze our home galaxy, they affect our observations of *millisecond pulsars*. These pulsars are rapidly spinning neutron stars that, like cosmic lighthouses on steroids, sweep beams of radio waves through space at a rate of several hundred pulses per second. Gravitational waves create tiny variations in the pulses' travel times that become apparent only over the course of many years.

Now, after decades of observations, astronomers are finally registering these slow spacetime ripples.

"When I first saw [the evidence], I was awestruck. It was a magical moment," says Maura McLaughlin (West Virginia University), codirector of the NANOGRAV collaboration. "For the first time, we now have good evidence for the existence of nanohertz gravitational waves. It's very difficult to explain [the observations] by any other process."

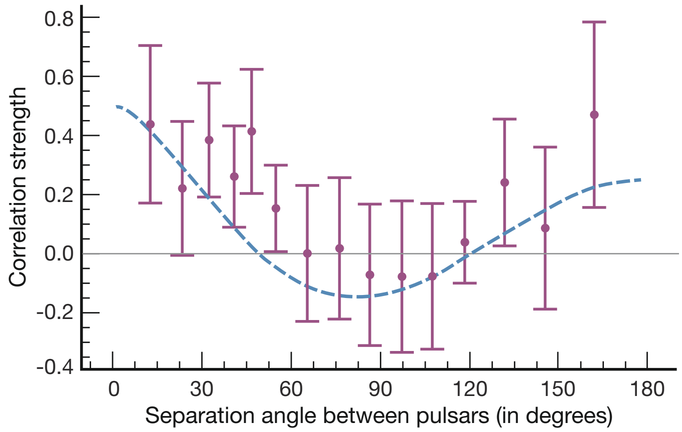
The NANOGRAV collaboration combined observations of 68 millisecond pulsars taken over the past 15 years by the 305-meter Arecibo Telescope in Puerto Rico, the 100-meter Green Bank Telescope in West Virginia, and the 27-element Very Large Array in New Mexico.

Likewise, the European Pulsar Timing Array (EPTA) collaboration combined data on 25 pulsars from the largest European radio observatories: Jodrell Bank Observatory in the United Kingdom, the Effelsberg radio telescope in Germany, Nançay Radio Observatory in France, the Sardinia Radio Telescope in Italy, and the Westerbork Synthesis Radio Telescope in the Netherlands. Scientists from India and Japan are also part of the EPTA.

Both the NANOGRAV and the EPTA collaborations report a nanohertz gravitational-wave signal in their data. According to NANOGRAV member Michael Lam (SETI Institute), the likelihood that the observed signal is due to chance is only about one in 1,000, corresponding to a better than three-sigma statistical significance. Similar projects carried out with the 64-meter Parkes radio telescope (Murriyang) in Australia and with the Five-hundred-meter Aperture Spherical Telescope (FAST) in China find consistent results.

While it's not yet possible to identify individual sources for these low-frequency waves, that may yet change. "The observed signal may well be dominated by just a handful of relatively nearby systems," explains EPTA member Alberto Sesana (University of Milano-Bicocca, Italy). "Right now, the evidence is inconclusive, but within a few years, we hope to get a better handle on this."

NANOGRAV



▲ **GALACTIC-SCALE DETECTOR** Gravitational waves should imprint a distinctive pattern of correlated timing variations, indicated by the dashed blue line. NANOGRAV results are shown in purple. Whereas the correlation should be strongest for pulsars near each other on the sky (with angles near 0°), variations in the signals from those separated by 90° on the sky will cancel out. In this way, the pulsars distributed across the Milky Way act like a many-armed gravitational-wave detector.

The detection is at the limits of what's currently possible, because even without gravitational waves pulse arrival times vary ever so slightly due to the motions of Earth and any individual pulsar through space. The pulsars themselves are also not perfectly stable rotators. To be sure of the detection, astronomers looked for patterns in the timing measurements for ensembles of pulsars. As gravitational waves ripple through our galaxy, pulsars near each other on the sky exhibit similar variations, while pulsars separated by 90° on the sky behave "out of sync."

A combined analysis of all the various pulsar timing array projects will continue to improve the result's statistical significance over the next one or two years. Additional pulsar data are also incoming. Astronomers add newly discovered millisecond pulsars to the roster on a regular basis.

New facilities are also entering the fray. While the 14-dish Westerbork array is no longer available for pulsar timing measurements, and the collapse of the Arecibo dish was a huge loss for NANOGRAV, other telescopes are under construction or already taking data. The Canadian Hydrogen Intensity Mapping Experiment (CHIME) joined NANOGRAV in 2019, and the Deep Synoptic Array-2000 (*S&T:* Sept. 2023, p. 14), to be built in Nevada, may also join. Meanwhile, China's FAST telescope continues to time pulsars, as does the 64-element MeerKAT array in South Africa. Before the end of the decade, the mid-frequency part of the giant Square Kilometre Array (*S&T:* June 2017, p. 24), which will incorporate MeerKAT, will become the most powerful observatory for these kinds of measurements.

■ Contributing Editor **GOVERT SCHILLING** is the author of *Ripples in Spacetime: Einstein, Gravitational Waves, and the Future of Spacetime* (Harvard University Press, 2017).

THE SUN NOW IN HIGH-DEF

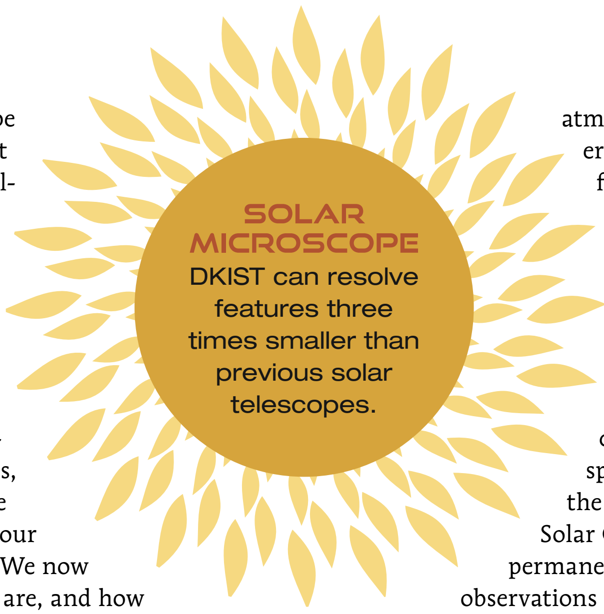
The new Daniel K. Inouye Solar Telescope is giving scientists an unprecedented view of our star.

The Sun is an ordinary G-type star, just one of billions that populate the Milky Way Galaxy. While it is not special in particulars, it is certainly important to us, for it gives light and heat to our little corner of the cosmos.

Our attempts to understand the Sun, both how it works and how it affects the local space environment, form a branch of science called *heliophysics* (from Helios, the Greek god of the Sun). Over the past century, our knowledge about our host star has grown exponentially. We now know why it shines, what sunspots are, and how streams (and occasional floods) of particles from the Sun fuel the aurora in our skies.

But as the saying goes, “The more you know, the more you realize you don’t know.” And there’s a lot we don’t know about the Sun. To narrow the gap, scientists are turning to innovative projects, with new solar telescopes and space probes promising better observations of the Sun than ever before. This revolution will be led in part by the Daniel K. Inouye Solar Telescope and its cutting-edge instruments. Named for the late Hawaiian senator and perched on the Haleakalā volcano on the island of Maui, DKIST just completed its first year of science operations.

DKIST was built, in large part, to support research into solar magnetism. The Sun has a strong and complex magnetic field that drives (and is driven by) internal processes, and magnetic activity powers everything in the solar atmosphere from heat flow to violent eruptions. As the Sun’s magnetic field propagates outwards, all kinds of dynamic transfers of energy occur. DKIST was designed with the investigation of these complex processes in mind.



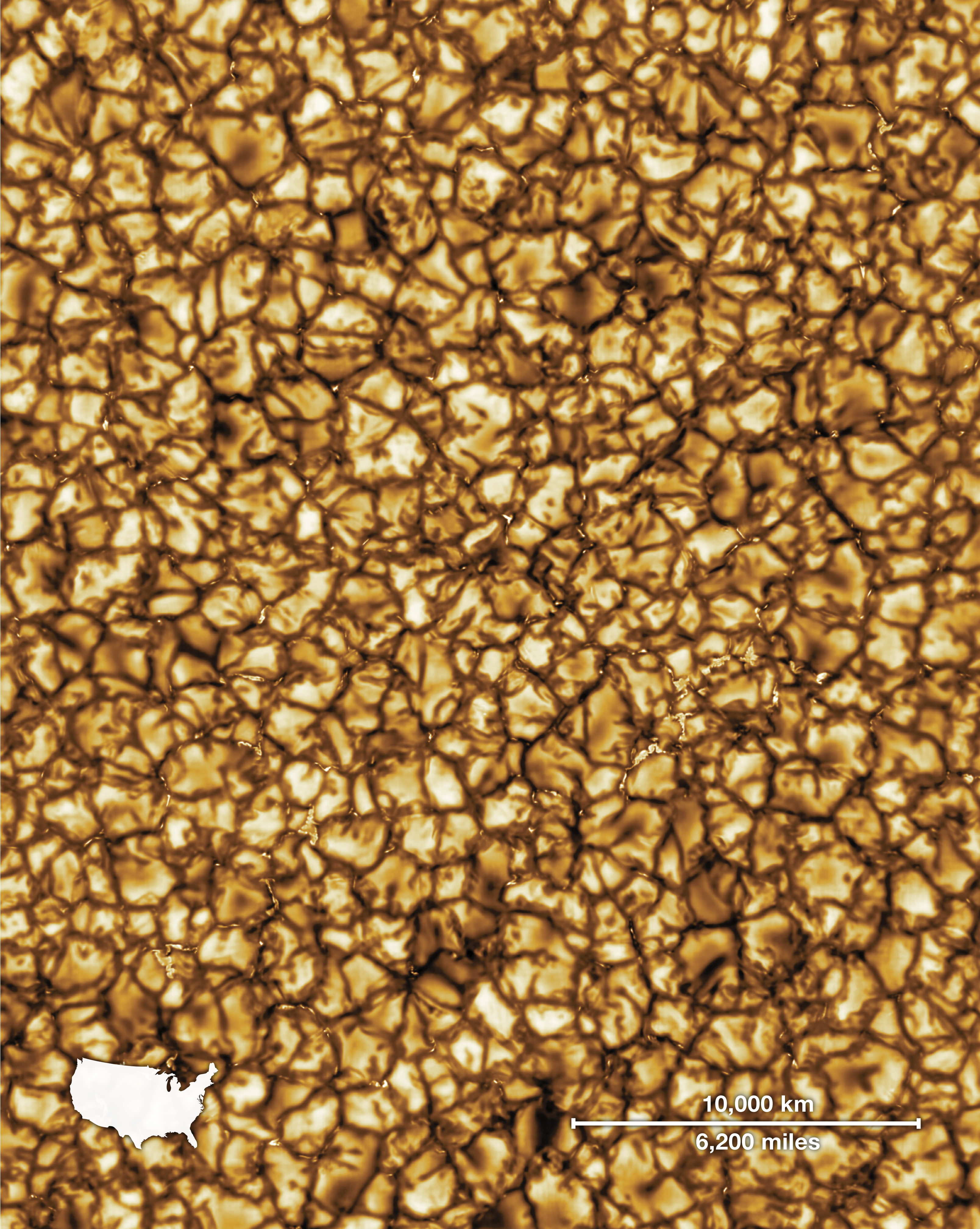
Soak up the Sun

In 1908, George Ellery Hale captured the first high-resolution spectroscopic images of the Sun with the Snow Telescope at Mount Wilson Solar Observatory — the world’s first permanently mounted solar telescope. Hale’s observations revealed fine structures around sunspots that looked a lot like iron filings sprinkled around a magnet. He went on to make the first measurement of polarization in a sunspot spectrum and correctly hypothesized that intense magnetic fields were responsible.

Since this seminal discovery, there have been many instruments built specially to study the Sun, even space probes like ESA’s Solar Orbiter and NASA’s Parker Solar Probe (*S&T:* Nov. 2020, p. 20). Numerous ground-based telescopes are dedicated to solar science, such as the Swedish 1-meter Solar Telescope on La Palma in the Canary Islands, completed

▶ **ZOOM GOGGLES** This image, taken at 789 nm, is one of the highest-resolution solar images ever taken. It reveals features as small as 30 km (18 miles) — 0.002% as wide as the Sun itself. Hot plasma rises in the convection cells’ bright centers, cools, then sinks in the dark lanes. Tiny, bright specks in these lanes come from concentrated magnetic fields, which may channel energy up to heat the corona.

SUN ICON: LIASHENKO IRYNA / SHUTTERSTOCK.COM; ZOOM IMAGE OF THE SUN: NSO / AURA / NSF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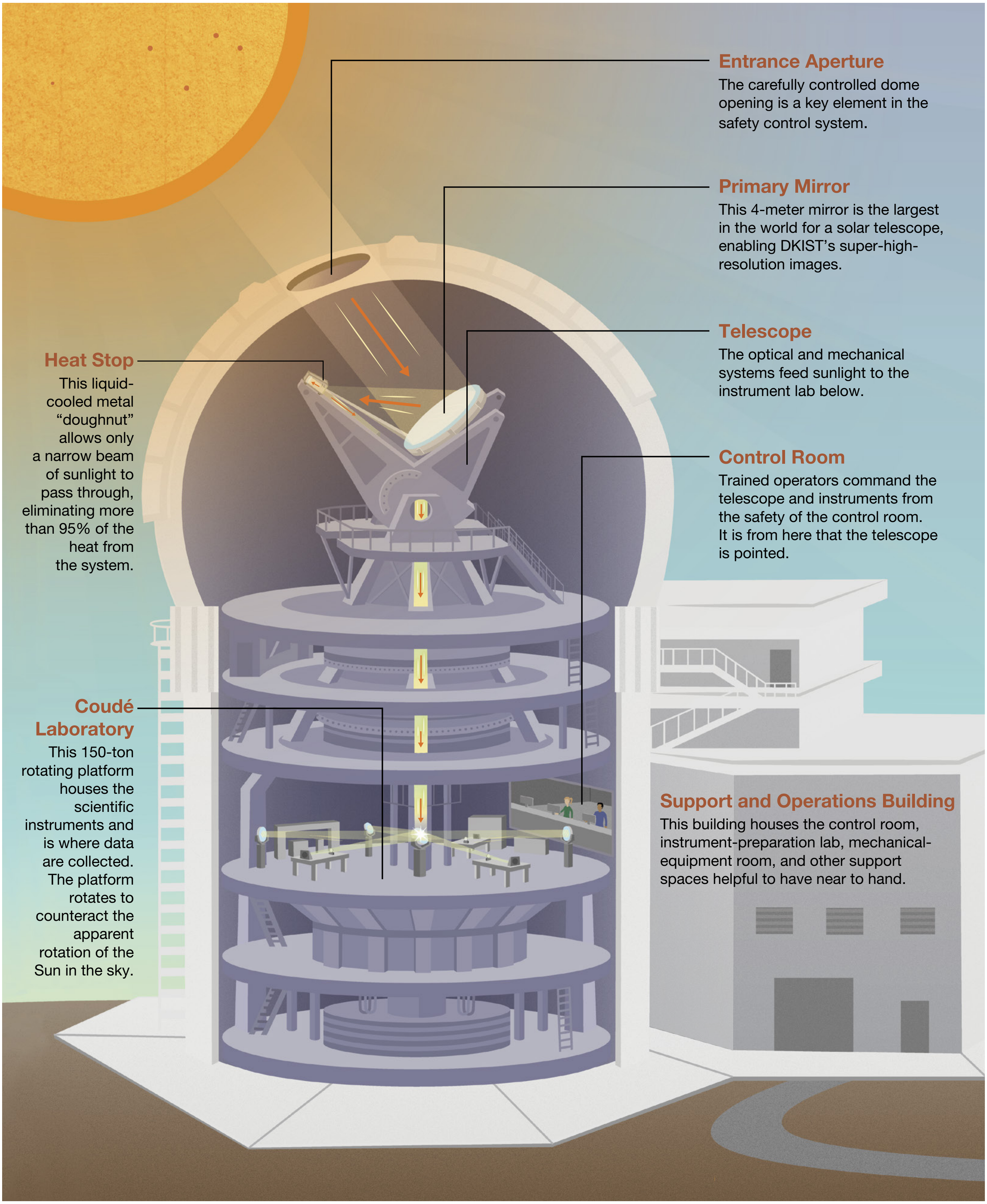

NSF / AURA / NSO

▲ **DKIST** A slice through the Inouye Solar Telescope shows the observatory's main sections, from the telescope's mirrors near the top to the Coudé instrument lab below. The dome stands more than 43 meters (140 feet) tall, or roughly 10 stories.

in 2002, and the 1.5-m Gregor Telescope just east of it on Tenerife, completed in 2012. DKIST joined the ranks in 2021.

DKIST has a 4-meter parabolic mirror that's more than double the size of previous solar telescopes' primaries and comes with cutting-edge stabilization, filtering, and cooling technologies, making it more powerful and adaptive than any solar telescope currently in operation. It is meant to be a kind of "microscope" for the Sun, with an unprecedented ability to zoom in on the surface, enabling detailed observations of the magnetic field and other dynamic behaviors. It can resolve features as small as 16 kilometers (10 miles) across on the solar surface, somewhat larger than the city of San Francisco; previous solar telescopes could only resolve features on a scale of roughly 100 km.

The design and operation of solar telescopes present unique challenges compared with dark-sky telescopes. Namely, solar telescopes must be able to withstand large amounts of heat. We are taught not to look right at the Sun, because it can hurt our eyes. The same is true for telescopes. The Sun emits a tremendous amount of energy and radiation, which can damage detector technology. To prevent this, DKIST has a specially designed facility and coolant system.

On the outside, DKIST's dome is covered by thin, actively cooled plates and shutters. Inside, the observatory has more than 11 kilometers of piping running throughout the walls, floors, and machinery. During observing hours a special kind of coolant — dynalene — flows through these tubes alongside the telescope's heat-sensitive systems and instruments, keeping them at room temperature.

The primary mirror is carefully chilled on both sides, by cold air behind and a liquid-cooled ring in front. Focused light from the primary is then directed towards the secondary mirror, where the beam would intensify even more. To mitigate this, a *heat stop*, a liquid-cooled, metal doughnut, sits between the mirrors and filters out more than 95% of the heat before it hits the secondary mirror.

So far, these cooling technologies have worked, and none of the telescope elements has suffered heat damage. But no system is foolproof. This is why sensors constantly monitor conditions in the observatory. If the temperatures within climb too high, safety covers deploy to protect the primary and secondary mirrors, and the dome automatically closes.

Here Comes the Sun

Kilometer by square kilometer, advancing technologies have zoomed in on the Sun. The hope is that a better understanding of what's happening on the smallest scales will help us make sense of how the Sun acts as a whole. DKIST, a project 30 years in the making, takes this approach to the next level.

The DKIST instrument suite is at the heart of the science mission. It includes an imager and four spectropolarimeters, which measure the Sun's magnetic properties. Each instrument plays a specific role in measuring the ever-changing conditions in the solar atmosphere, from the visible surface (the *photosphere*) to the outermost atmosphere (the *corona*). They are housed in a 16-square-meter (170-square-foot), rotating clean room located directly below the observing platform, called the Coudé Laboratory.

Light from the telescope is directed downwards from the secondary mirror and through a complex system of mirrors. Then it passes through an *air knife* — a barrier created by a steady, rushing stream of air — before entering the lab through a hole in the ceiling. The air knife acts to separate the observatory environment from the lab below. This is necessary because the observatory is open to the outside, and conditions on the platform can vary by season and time of day — whereas the instrument lab requires a dust-free environment with a stable room temperature of 20°C (68°F) to ensure everything works properly. Typical cleanrooms use glass or plastic barriers, but these would absorb infrared light from the Sun, which scientists want to study. Air knives are most commonly used in manufacturing; this is the first time one has been used in a solar telescope.

As the intensified light from the Sun shines down through the ceiling aperture into the Coudé, it looks futuristic, like a transporter beam from *Star Trek*. Before the sunlight hits the instrument table, it encounters a deformable mirror. The purpose of this technology is to cancel out the effects of Earth's atmosphere on the light. A series of tiny pistons continuously skews the mirror's surface according to a complex computer algorithm, changing the mirror's shape up to 2,000 times per second. Imagine wearing a pair of swimming goggles that corrects for underwater light distortion, allowing you to see as

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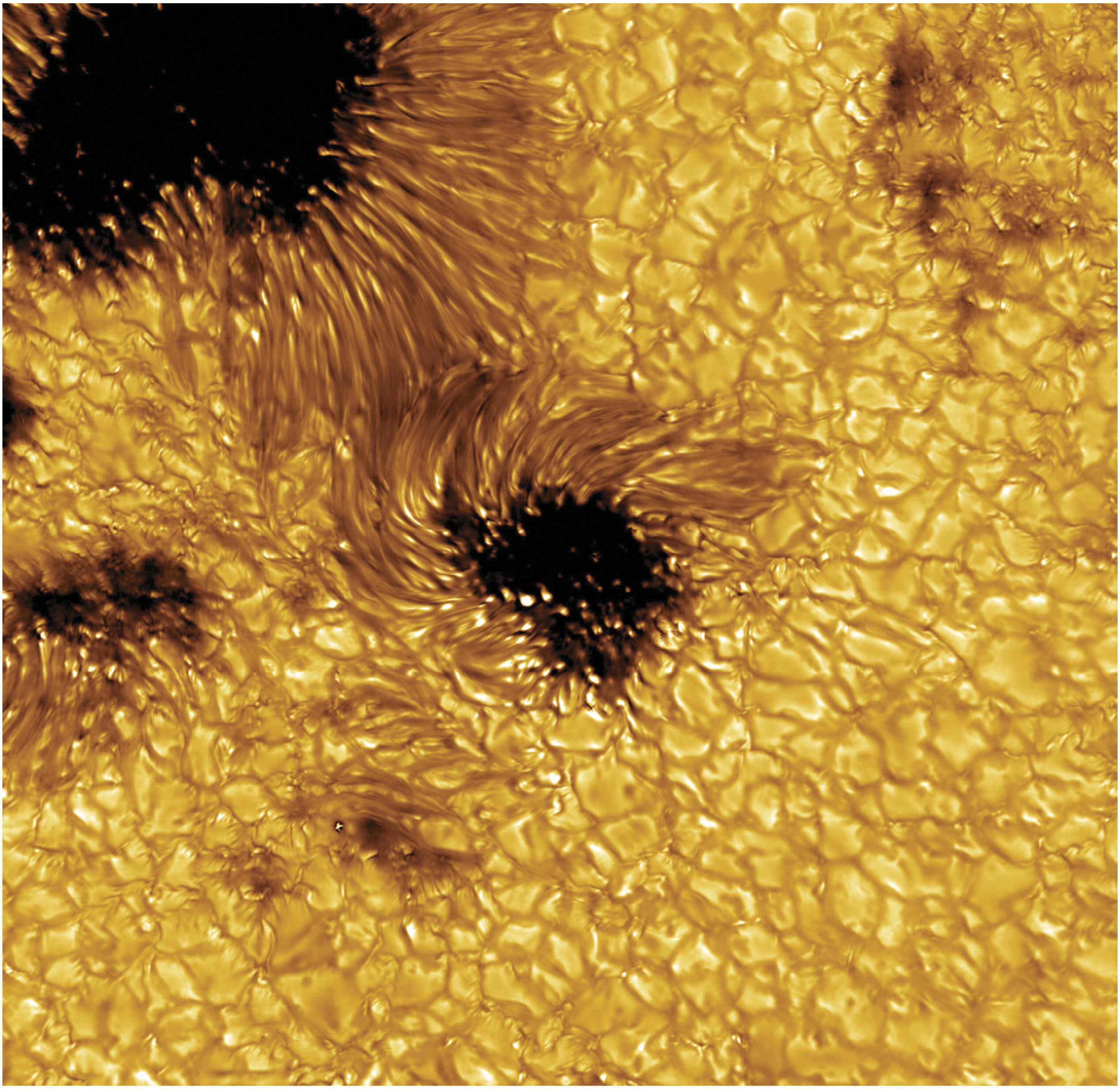
▲ **EYE OPEN** DKIST stands with open aperture beneath a blue sky near the summit. A series of windows called vent gates enables operators to control the temperature and airflow inside the enclosure, keeping equipment stable in a variety of conditions.



▲ **SUNSPOT CLUSTER** This DKIST image from May 11, 2021, derives from data taken with the Visible Broadband Imager at a wavelength of 450 nanometers. The full cluster was larger than Earth.

NSO / AURA / NSF

clearly and as far as you can on land. Metaphorically, this is what DKIST's adaptive optics are trying to achieve — reverting the light to the way it looked before it hit Earth's atmosphere.

Precisely positioned mirrors and filters then split the sunlight so that DKIST's five unique cameras each receive a dedicated beam. In this way, astronomers can make disparate spectroscopic and polarimetric observations simultaneously, according to the particular purpose of each instrument.

Science Operations Commence

DKIST completed its first full year of scientific operations in February 2023, executing observing programs requested by scientists from all over the world, says director Thomas Rimmele (National Solar Observatory). The first round of scientific operations utilized only three instruments, and the fourth instrument was only recently installed. The final one to integrate is the VTF, the Visible Tunable Filter, which should be in place in early 2024.

Observatory personnel have done plenty of troubleshooting as they iron out the kinks, including putting work on hold

until they could sort out mechanical problems. "I remember one day the images were very jittery," Rimmele says. "It turned out new cooling fans were installed in an electronic cabinet, and it introduced vibrations all through the mechanical structure into the optics. There is a continuous stream of problems like this that we are still addressing and fixing, almost on a daily basis."

Nevertheless, DKIST has already provided valuable data. The upcoming results of the first round of observations promise to tell us more than ever before about our host star. Scientists are especially optimistic that investigations into flares and mass ejections, the solar wind, and heating processes in the Sun's atmosphere will soon yield answers to looming questions. They may even enable better space-weather predictions.

Heat Wave

For some unknown reason, the corona is millions of degrees hotter than the layers directly below it. You might think that the temperature would just get cooler and cooler as you move outward from our star's center, but it's not that simple.

The core is by far the hottest part of the Sun, at 15 million degrees Celsius. Subsequent layers do cool off, with the photosphere measuring only 5500°C. But after that, things change. Just above the photosphere, the chromosphere averages a bit hotter, 6000°C. Then in the thin transition region between the chromosphere and the corona, there is a sudden, significant rise in temperature to 1 million degrees. The corona itself ranges between 1 and 2 million degrees.

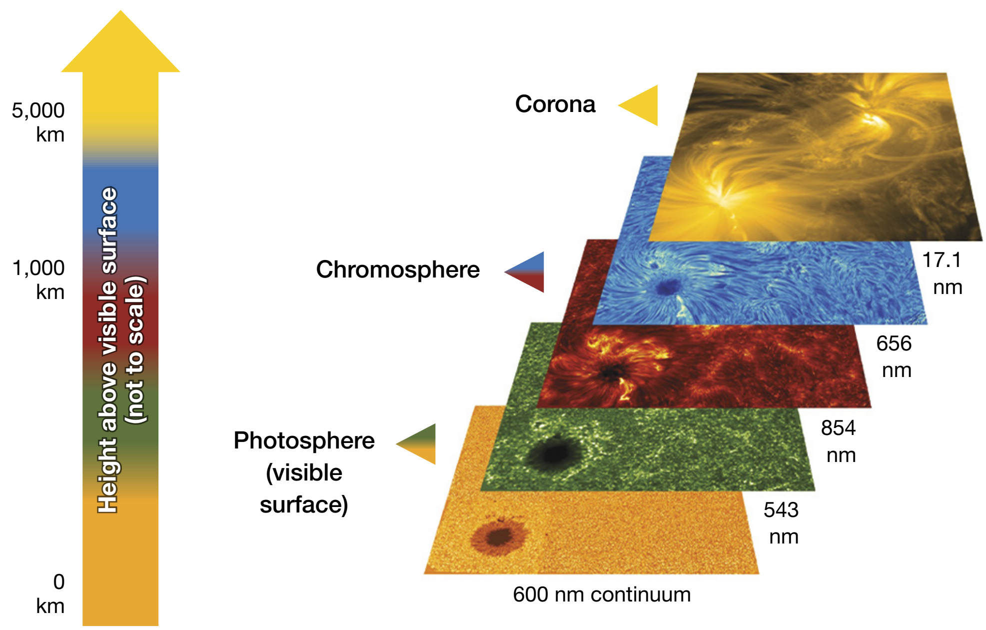
There's no straightforward explanation — certainly there are no nuclear reactions, like in the core. Solar scientists have several theories, all connected in one way or the other to magnetic fields, which can carry and release energy that heats surrounding plasma. *Wave heating* and *magnetic reconnection* are two favored mechanisms.

Wave heating works via the convective motions of plasma in the photosphere, which propel magnetic "disturbances" all the way through to the corona. There, the wave energy dissipates, heating the atmosphere. Magnetic reconnection, on the other hand, involves the way that the Sun's magnetic field lines tangle and snap into new arrangements. Heliophysicists think that the energy released in this process could result in small-scale heating events called *nanoflares*. Astronomers have observed both waves and reconnection events, but drawing a straight line between these phenomena and coronal heating is not a simple task. It is also possible that these are just two of many mechanisms that contribute to coronal heating.

This is where DKIST comes in.

Astronomers took first-light images of the Sun with DKIST's Visible Broadband Imager (VBI), a high-speed camera that can resolve areas of the solar surface and lower atmosphere as small as 16 kilometers across. Researchers designed it specifically to study sunspots and other features on the Sun's surface over time. These inaugural images show a distinctly granulated pattern of boiling plasma, which rises in the cells' centers and then cools off and sinks below the surface in the darker sections between the granules. The cells are each about the size of Texas, and the dark lanes between bear tiny, bright markers of magnetic fields. Never before seen at such high resolution, these glowing sparks appear to show energy being channeled up from the surface into the corona, perhaps acting as *wave guides* — structures formed by concentrated magnetic fields that shepherd waves into the Sun's atmosphere. More observations and study of this phenomenon could help to support wave-heating theories.

Meanwhile, other DKIST work may support reconnection's role instead. Research by Ryan Campbell (Queen's University Belfast) and others in his group suggests that magnetic reconnection and subsequent heating of the corona could be facilitated by tiny little energy loops called *magnetic bipoles*, which constantly cover the whole surface of the Sun. When the loops' fields reconnect, magnetic energy converts into radiation and kinetic energy, producing nanoflares that might help heat the solar atmosphere. The telescope's microscopic capabilities are key to these investigations.



▶ **CHANGING VIEW** This series of images shows how a sunspot looks in different layers in the solar atmosphere. The photosphere and chromosphere images come from the Dunn Solar Telescope in New Mexico; the corona image comes from NASA's Solar Dynamics Observatory.

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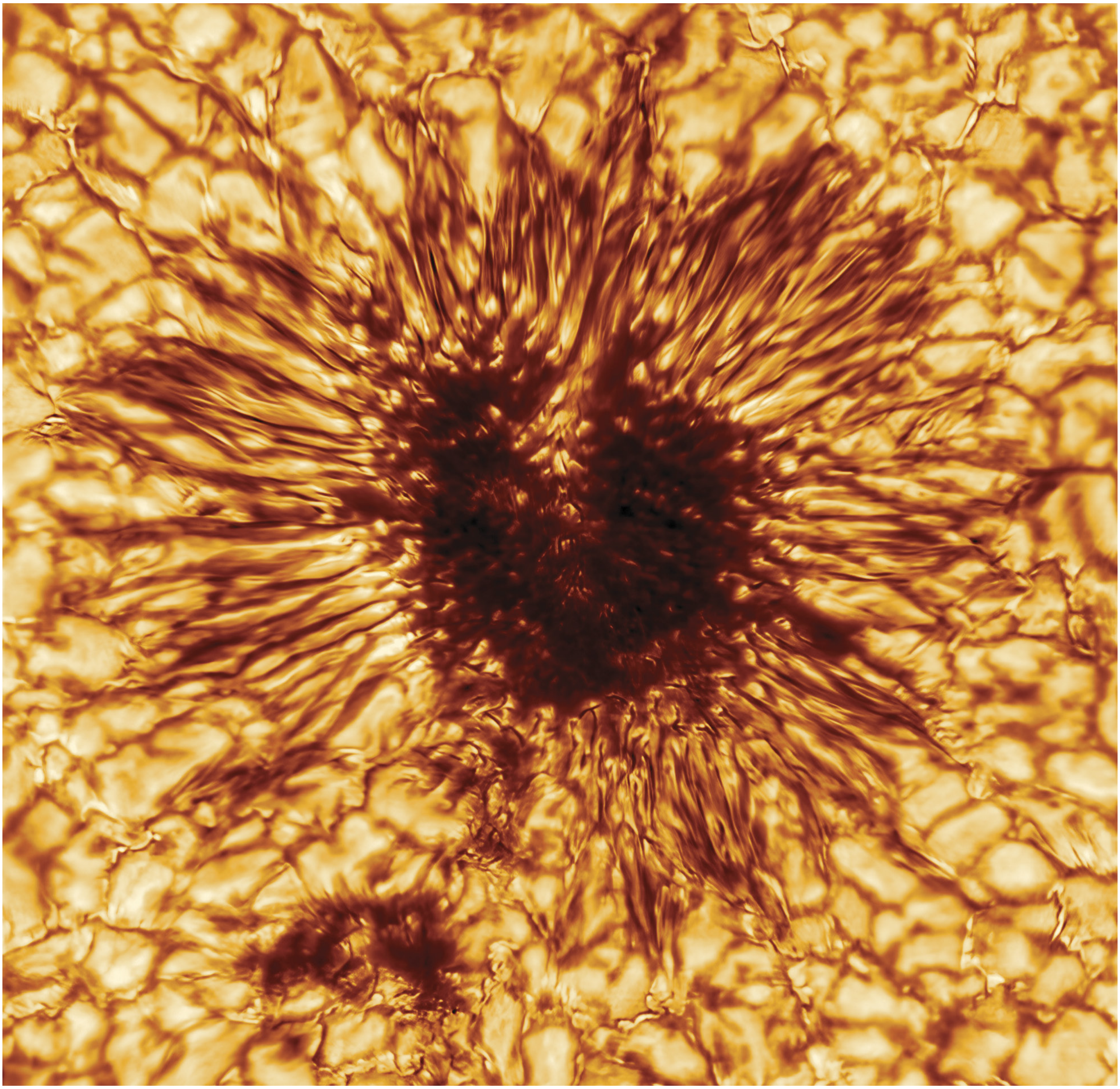


▲ **THE FIRST SUNSPOT** This color-adjusted image is the first taken by DKIST of a sunspot, at a wavelength of 530 nm. The heart-shaped umbra is the size of the contiguous United States.

NSO / AURA / NSF

"My opinion," Campbell says, "is that you have to start with the building blocks of the solar atmosphere — what's happening with the magnetic field on the smallest scales in the photosphere. And you have to build the picture up from that point, if you want to try and solve the problem."

Building the picture also requires multiple perspectives. Rimmele has used his director's discretionary time to organize coordinated observations of the corona with Parker Solar Probe and Solar Orbiter. Parker flies through the outer corona, while Solar Orbiter measures particles from the Sun (particularly the poles) blowing through the solar system. The goal is to build a 3D understanding of coronal magnetic structure by combining the view from Earth with those from spacecraft on different orbits.

Gone with the Wind

The ubiquitous effects of the Sun go beyond temperature alone. In 1959 the Soviet spacecraft Luna 1 detected a strange flow of charged particles while en route to the Moon. This was the first direct observation of what we now call the solar

wind — a continuous stream of plasma, consisting mostly of protons and electrons, which emanates from the Sun's corona in every direction.

Of particular interest to us is how the solar wind influences the space environment around Earth, interacting with our planet's magnetic field and causing phenomena such as geomagnetic storms and aurorae (*S&T:* Oct. 2023, p. 11). Scientists still don't fully understand the exact mechanisms for how the solar wind forms or how it accelerates to high speeds. Synergistic observations with the Parker Solar Probe, Solar Orbiter, and DKIST could support the hypothesis that small-scale magnetic activity on the surface ("jetlets") and the solar wind are connected, by providing causal evidence that certain structures in the wind originate from specific magnetic events.

The Sun's polar fields appear to channel most of the fast solar wind, and one of the first-round proposals, led by Gordon Petrie (National Solar Observatory), seeks to study this. Previous observations do not have sufficient resolution or sensitivity to map the magnetic field all the way to the poles. But observations with DKIST just might do the trick.

WARNING: Space Weather

The more explosive effects of solar magnetic fields are of particular interest when it comes to flares and ejections of particles and plasma, which can be dangerous for Earth. Scientists think flares and *coronal mass ejections* (CMEs) are caused by the release of magnetic energy stored in the Sun's atmosphere. During these events, *solar energetic particles* (SEPs) somehow become accelerated in the Sun's atmosphere to fair fractions of the speed of light, then ride along the Sun's magnetic field lines into interplanetary space.

We have been able to routinely observe and study CMEs since 1995, when the joint ESA–NASA Solar and Heliospheric Observatory (SOHO) launched. There are also several "big-picture" solar telescopes (as opposed to DKIST's micro approach), including NASA's Solar Terrestrial Relations Observatory (STEREO), which studies events like solar flares and CMEs.

These dramatic explosions can have detrimental effects on technology on and around Earth, if they are powerful enough. Another flare equivalent to the Carrington Event of 1859 would be devastating to our modern telecommunications and energy infrastructure. So it is of great interest, not just to astronomers, but to corporations and governments as well, to be able to predict and prepare for this eventuality.

The impact of flares, CMEs, and SEPs on Earth depends on various factors such as the intensity of the event and the direction of the solar particles. The better we understand the processes that lead to the formation of all these events, the better our predictive capabilities and mitigation response for adverse space weather events will become.

To this end, the National Solar Observatory (which operates DKIST) sends data to the National Oceanic and Atmospheric Administration's Space Weather Prediction Center, the U.S. Air Force, and NASA, so that they can try to predict things like geomagnetic storms. Since 1995 the NSO has used six identical telescopes placed around the world, called the Global Oscillation Network Group (GONG), to gather the necessary data. DKIST will provide a complementary view of the Sun and the solar conditions that lead to hazardous space weather.

One of DKIST's goals this first year was to observe a flare from beginning to end, and scientists were lucky enough to do so. Adam Kowalski (University of Colorado, Boulder) headed up a study investigating how the intense heat in the corona is transported back down through the chromosphere, and whether this process might be the origin of some powerful flares and CMEs. While his group has not yet finished analyzing the data from the flare they observed, he says the results look very promising.

"I think that soon we will have a much better understanding of the conditions that lead to solar flares," he says. "Meaning, when looking at an active region, we'll have a better idea, through the spectra, of the densities and temperatures in the low chromosphere, and how they line up before and evolve during a really big flare."

Dawn of a New Era

There are big questions about the Sun's magnetic fields and how they influence coronal heating, the solar wind, and space weather, and solar scientists designed DKIST specifically to find the answers. The core science plan also includes topics such as how the Sun generates its magnetic field, the evolution and fine structure of sunspots, and magnetic field structure and dynamics. DKIST should also be able to tackle very-long term observation projects and investigate tangential subjects of broad interest.

The operational lifetime of DKIST is meant to be 44 years, at least two full solar-activity cycles. This will enable us to learn more about the changes in radiation, sunspot activity, flares, and coronal-loop fluctuations that occur every 11 years as the Sun's magnetic polarity flips. Intriguing opportunities will arise for studying Mercury when it transits the Sun in 2049 and 2052.

In addition, scientists hope to use DKIST to study sungrazing comets. Previous studies suggest that their passage through the corona can act as a kind of probe to help us estimate the corona's density and temperature and the velocity of the solar wind.

Once upon a time, the nature of the Sun was so outside of our ability to understand, it was ascribed mystical or religious properties. But times change. New technology allows us to look at the Sun without going blind, observe the invisible motions of its magnetic fields, and even sense the motions of the turbulent plasma within. And little by little, the mysteries of our host star are being revealed.

■ **ARWEN RIMMER** is a writer and musician based in Cambridge, England.

A Clockwork Cos

The Antikythera Mechanism is a remarkable meld of mathematics and precision engineering.

In 1900 sponge divers discovered an ancient shipwreck off the tiny Greek island of Antikythera. Over the course of the following year, in the first major underwater archaeology ever undertaken, they salvaged numerous objects from the wreck. Among them were what turned out to be the remains of a device that computed and displayed the positions of the Sun, Moon, and planets. Coins recovered from the same shipwreck indicate that it sank around 60 BC, meaning that the Antikythera Mechanism, as it's now known, contains the oldest gears ever found — at least 30, and originally there were probably more than twice that number. It's by far the most complex machine known to have been built before the late Middle Ages, when it was surpassed by astronomically themed clocks.

The Mechanism attracted little notice at first, possibly because its innards were hidden inside a single, encrusted lump of corroded bronze. The first photograph, taken in 1902, shows four fragments with many eye-catching gears. The original lump may well have broken apart when it was exposed to air since most of the original bronze had been replaced by fragile corrosion products during the device's two millennia under water. In addition to several large pieces, there are now many tiny fragments resulting either from intentional dissection or accident. Fortunately, most of the remnants have preserved their original shape and internal structure surprisingly well.

Scholars made considerable progress understanding the Mechanism over the years, but their conclusions remained tentative until three rounds of X-ray imaging revealed numerous details *inside* the fragments. The last of these sessions in 2005 used advanced tomography techniques that proved successful beyond any reasonable expectation. Together with state-of-the-art optical imaging, it revealed a wealth of inscriptions, some on the surface and others buried deep inside the fragments. The multidisciplinary team assembled to perform the 2005 study published their results in a 2006 paper in *Nature*, which included a detailed description of much of the original gearwork together with the device's overall layout and function. All the team's major conclusions are now universally accepted.

It turns out the Mechanism included two bronze sheets, which presumably protected it in transit. These sheets are filled with writing — what Tony Freeth (University College London), the lead author of the paper, refers to as its "owner's manual." Much of the text is too degraded to read, but the part that has been deciphered gives a pretty clear idea how the device worked. The latest reconstruction (presented below, right, and on page 26) by Freeth and others appeared in a 2021 article in the journal *Scientific Reports*.

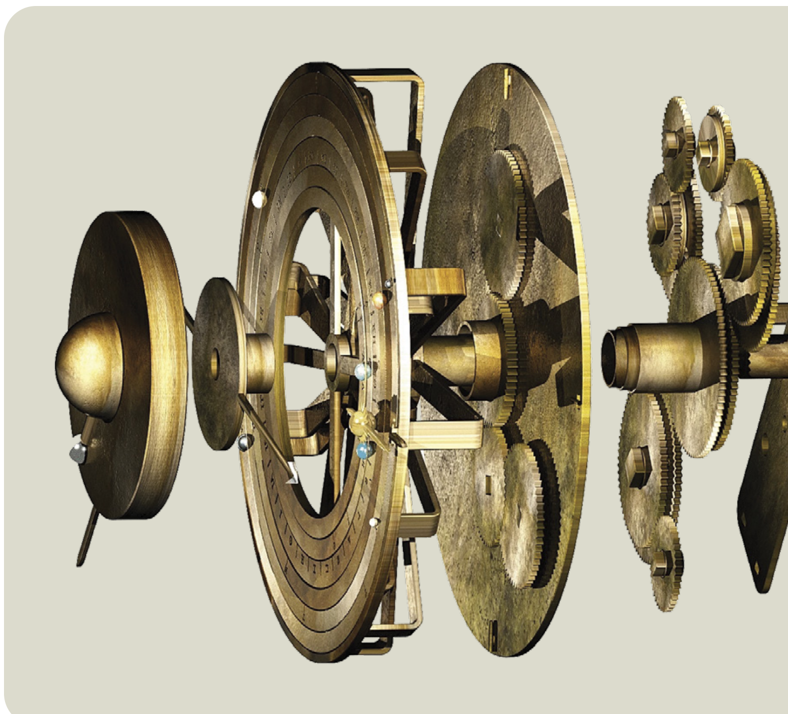
Calendars and Eclipses

The Antikythera Mechanism was roughly 33 cm (13 inches) high, 18 cm wide, and perhaps 10 cm thick. It had a knob or crank on the side that advanced the date by about 78 days per rotation. The user, in theory, could go indefinitely far into the future or past, though this would get tedious at almost 500 cranks per century.

Most of the back plate was occupied by two spiral grooves. Each spiral was marked off in increments corresponding to *synodic months* (new Moon to new Moon). The upper and lower spirals showed 235 months (the *Metonic period*) and 223 months (the *saros period*), respectively.

A stylus mounted on a gear-driven arm tracked outward along each spiral as the date advanced. The instructions note that when the stylus reaches the end of the groove, the operator should lift it out and re-insert it at the beginning, much

FRONT AND EXPLODED VIEWS: © 2021 TONY FREETH (2)



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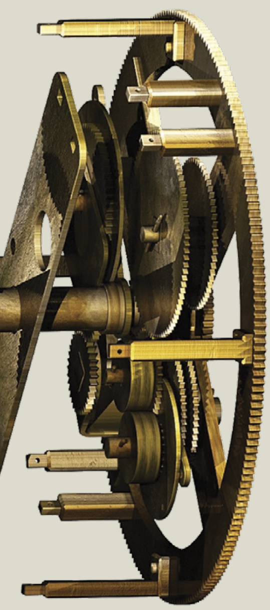
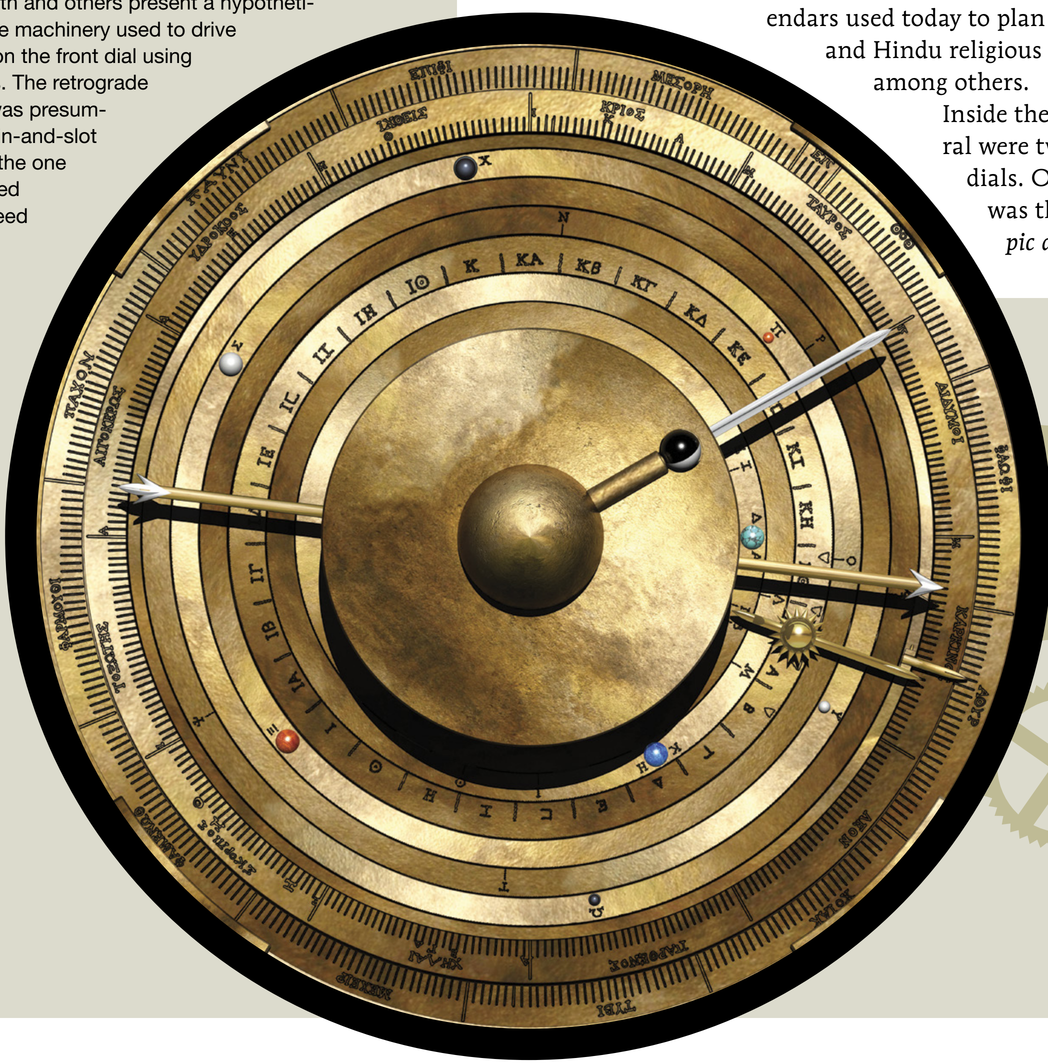
▼ **BRONZE BEAUTY** *Right:* The Antikythera Mechanism, constructed some time before 60 BC, computed the positions of the Sun, Moon, and planets. In 2021, Tony Freeth and others published an article presenting a tentative reconstruction of the front part of the Mechanism, most of which is lost. Working from the center out, we have the stationary dome of Earth and the Moon pointer that features a black-and-white bead showing the current phase. Next are a series of rotating rings adorned with colored beads for Mercury, Venus, a golden Sun, Mars, Jupiter, and Saturn. Also included are a date pointer (just above the Sun hand) and an index showing the ecliptic marked off in signs and degrees as well as the Egyptian calendar. The double-headed pointer (slightly off horizontal) indicates the line of nodes.

▼ **COMPUTATIONAL COMPLEXITY** *Left:* In their 2021 article in *Scientific Reports*, Freeth and others present a hypothetical reconstruction of the machinery used to drive the pointers and rings on the front dial using 34 tightly packed gears. The retrograde motion of the planets was presumably computed using pin-and-slot mechanisms similar to the one known to have computed the Moon's variable speed through the stars.





like replaying a phonograph record. This made it possible to advance through multiple Metonic and saros cycles.

The top spiral was inscribed with the names of months from the civil calendar of some unknown Greek city-state, likely in Epirus near the current border of Greece and Albania. Bear in mind that at the time there was no standard Greek calendar — each of the hundreds of squabbling city-states that we now call Ancient Greece had its own system, and often more than one. Like most Mediterranean civilizations before the Roman Empire, the Greeks used lunisolar calendars in which each month matches one Moon-phase cycle. Most years contain 12 full months, but some include an additional leap month to ensure synchronization with the seasons.

Leap months were originally imposed by decree whenever the dates of planting and harvest started to slip too much. However, that made it impossible to refer reliably to dates in the future. Around 500 BC astronomers in Mesopotamia discovered that 235 synodic months — an interval later called an Metonic cycle — is almost exactly equal to 19 years (actually 19.0002 years). This initiated a trend toward preplanned lunisolar calendars that add 7 leap months every 19 years in a fixed pattern. The calendar shown on the Mechanism's upper spiral is of this type, as are the calendars used today to plan Jewish and Hindu religious festivals, among others.

Inside the upper spiral were two small dials. On the left was the *Callippic dial*, with

a pointer making one circuit every 76 years — precisely four resets of the Metonic stylus. That fixed a flaw in the Metonic cycle caused by the fact that a year is about a one-quarter day longer than 365 days. Nineteen isn't divisible by four, so the Metonic cycle falls one-quarter day short of the nominal 6,940 days, requiring one day to be removed from every fourth Metonic cycle to stay in sync with the seasons.

On the right was a *Games dial* (appropriately for sports-mad ancient Greece). Its pointer rotated once every four years, indicating selected major sporting events for each year of the *Panhellenic* (all-Greek) Games cycle. The Panhellenic Games had near-sacred status because they were among the few institutions that united the Greek city-states. The founding of the Olympic Games, purportedly in 776 BC, was widely considered to be Year One of Greek civilization.

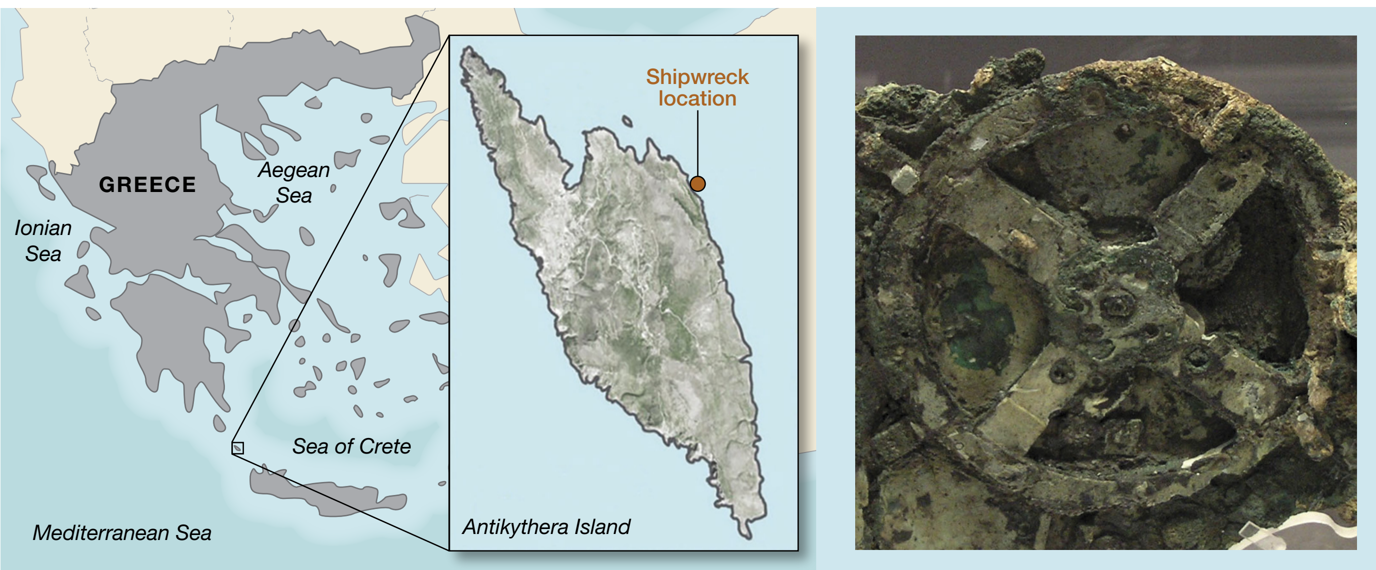
The bottom spiral showed what eclipses could be expected in each month of the 223-month saros cycle. Only a few months have eclipses, so most of the cells were empty. For months when one or more eclipses were expected, the cells stated the possible eclipse types and expected times. To see why a single 223-month spiral is sufficient, consider how eclipses work. (Greek astronomers well understood all of this by the time the Mechanism was built.)

Lunar eclipses can happen only at full Moon, when our satellite is opposite the Sun's position in the sky. Likewise, solar eclipses can happen only at new Moon. The fact that the Moon's orbit is inclined 5° with respect to Earth's path around the Sun means that in addition to being full or new, the Moon must also be passing through the plane of Earth's orbit, which is sometimes called the *ecliptic plane* for that very reason. The time it takes for the Moon to cross up, down, and up again through the ecliptic is called a *draconic month*, after the mythical dragons that supposedly swallow the Sun or Moon during an eclipse. Eclipses repeat every saros cycle due to the fact that 223 synodic months equal 241.999 draconic months and 238.992 anomalistic months. (More about anomalistic months later.)

What that means in practice is that if the Sun, Moon, and Earth line up to produce an eclipse, they will (except in marginal cases) produce a very similar eclipse 223 months later. A sequence of eclipses separated by intervals of 223 months (18.03 years) is called a *saros series*. Saros series only last about 12 or 13 centuries because the various periods involved don't line up perfectly. A saros series starts and ends with a thin partial eclipse, with the longest and fullest eclipse near the center. The saros period is about 8 hours longer than an integral number of days, so every third eclipse in a saros series occurs at roughly the same time of day ($3 \times 8 = 24$ hours). That's another way of saying that Earth is oriented roughly the same with respect to the Sun, meaning that every third eclipse is visible from roughly the same locations. For instance, the total solar eclipse on March 7, 1970 peaked over Mexico, as will the one on April 8, 2024, three saros cycles (54.1 years) later.

So just as four passes through the Metonic spiral have special significance for calendars, three full passes through the saros spiral have special significance for eclipses. And sure enough, there was a little dial inside the Mechanism's bottom spiral whose pointer rotated once every 54.1 years. It was divided into thirds marked empty, 8, and 16, showing the number of hours to be added to the time of day listed in each eclipse cell.

All five dials on the back rotated at fixed ratios, just like the hour and minute hands on a clock, though with more complicated periods. The gearing is conceptually straightfor-



▲ **TREASURE ISLAND** *Left:* The tiny island of Antikythera, which lies in the middle of the shipping lane from the Adriatic Sea to the western Mediterranean, has been the site of numerous shipwrecks. *Right:* X-ray tomography revealed that Fragment A, the largest of the 82 surviving fragments of the Antikythera Mechanism, contains part or all of at least 29 gears. The big gear prominently displayed on the front is about 125 cm (5 inches) in diameter and originally had 223 or 224 teeth.

MAP: BEATRIZ INGLESSIS / *S&T*; MECHANISM FRAGMENT: WIKIMEDIA COMMONS / CC BY 2.5

ward, though packing the necessary gears into the available space required great ingenuity.

The front plate showed the positions of the Sun, Moon, and planets in the zodiac. Displaying this information correctly presented an entirely different problem because each of those bodies moves at variable speeds. Let's take a look at the mathematics that astronomers used to explain that fact in 60 BC before seeing how it was implemented in bronze.

Eccentric Circles

Astronomy flowered as never before during the Hellenistic period that followed the death of Alexander the Great in 323 BC. Greek astronomers had always been accomplished at abstract reasoning and geometry. For instance, they were the first to realize that eclipses are caused when the Moon passes into Earth's shadow and vice versa. But they tended to have a casual attitude toward data before Alexander's conquests brought them into direct contact with Mesopotamian civilization, the world's oldest. Babylonian astronomers — as they're usually called, even though most of them worked outside the city of Babylon — started recording a series of continuous, consistent astronomical observations around 650 BC, resulting in a wealth of empirical data. They were also brilliant at detecting mathematical patterns within the data, including the Metonic and saros cycles, though they apparently never sought to examine the underlying causes.

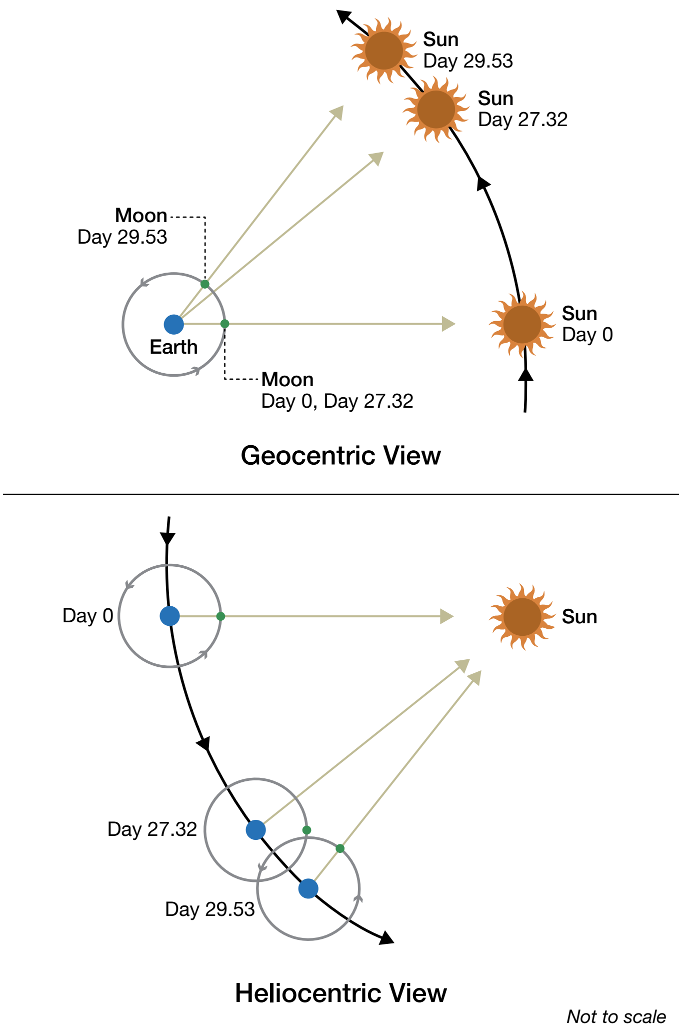
Hipparchus (c. 190–120 BC) is widely credited with combining Babylonian data analysis with the Greek flair for theory to create geometric models that could accurately forecast the motions of the Sun and Moon for many centuries into the future. His models worked beautifully despite being based on several false assumptions.

With the striking exception of Aristarchus of Samos (c. 310–230 BC), Hellenistic astronomers erred by assuming that Earth was stationary instead of in orbit around the Sun. That assumption creates major problems for predicting the motions of the planets, but as far as the Earth-Moon-Sun system is concerned, it makes no difference at all whether the Sun orbits Earth, or vice versa, as shown in the diagram at right.

Nonetheless, Hipparchus had a number of embarrassing anomalies to explain. Observations proved that both the Sun and Moon move through the "fixed" stars at slightly variable rates. This clashed with the deeply rooted Greek conviction that all celestial objects travel in circles at uniform speeds. His solution was simply to place Earth a little off-center. That way, the Sun and Moon *appear* to move faster when they're closer to Earth. And he was partly right. Half the variation in the Sun's and the Moon's angular motions are due to this perspective effect, while the other half is due to the fact that celestial objects actually do move fastest at the closest points of their orbits, as Johannes Kepler and Isaac Newton proved almost two millennia later. But Hipparchus compensated by assuming twice the actual eccentricity, yielding results essentially identical to Kepler's.

Today we know that orbits are elliptical rather than circular, but the difference between ellipses and off-center circles is barely perceptible. Mercury's orbit has an eccentricity of 0.206 — the biggest of any planet. That means the Sun is displaced a whopping 20.6% from the geometric center of Mercury's orbit. Yet it's out-of-round by a barely perceptible 2.1%. The orbits of the Moon and Earth are flattened just 0.15% and 0.01%, respectively. So, using eccentric circles yields almost exactly the same answers that using ellipses would have.

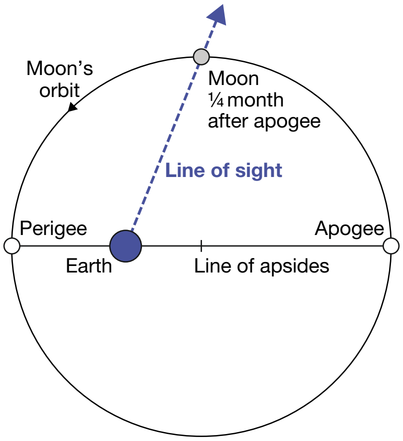
The gears driving the Sun pointer on the Mechanism's front dial are lost, so we can't be sure that it moved at a nonuniform rate. But enough of the Moon gearing survives to



▲ **ROTATIONAL RELATIVITY** The diagram on top shows why the 29.53-day synodic month is longer than the 27.32-day sidereal month based on the ancient Greek assumption that Earth lies stationary at the center of the universe. After 27.32 days the Moon makes one full orbit and returns to the same position, but in that same time the Sun has advanced about 1⁄12 of the way on its orbit around Earth. It takes the Moon an additional 2.21 days to catch up. It's conventional today to depict the same scenario based on the assumption that the Sun is stationary, as shown below. As the ancient Greeks were well aware, the two models yield identical predictions. The geocentric model is more convenient for describing the Earth-Moon-Sun system, but the heliocentric model is vastly superior for describing the motions of the planets, a fact that eluded the Greeks.

BEATRIZ INGLESSIS / S&T

reconstruct its workings with confidence, and it did indeed use an eccentric circle to mimic the lunar anomaly. This was accomplished with two gears with parallel faces connected by a pin on the driver running through a slot in the driven gear. The axles of the two gears were offset by about 1.1 mm, and the pin was about 9.6 mm from its axis, yielding an eccentricity of 1.1/9.6, which is about 0.115 — almost exactly the right amount to explain the lunar anomaly.



◀ **ECCENTRIC CIRCLES** Ancient Greek astronomers often explained the varying speeds of celestial objects through the zodiac as the result of eccentric (off-center) circular orbits. A quarter sidereal month after the Moon is at apogee (farthest from Earth), it has traveled precisely one-fourth of the way around its circular orbit, but an observer on Earth sees it as having traveled less than 90° against the distant stars due to perspective effects. (The Moon's eccentricity is greatly exaggerated for clarity.)

The pin in this system rotates in a circle at uniform speed around the driver's axle, just as the Moon in Hipparchus's model rotates uniformly around its orbit's center. The off-center axle of the driven gear corresponds to Earth, and its groove corresponds to an earthly observer's line of sight. Both gears turn at the same rate on average, but the driven gear rotates fastest when the pin is closest to its axle and slowest when the pin is farthest.

In addition, the entire ellipse rotates around Earth so that the *line of apsides*, which connects *perigee* and *apogee* (the points of closest and farthest approach, respectively) makes one full circuit every 8.85 years. During the time required for the Moon to reach two successive perigees (the *anomalistic month*), perigee itself has advanced a little with respect to the distant stars. That's why the anomalistic month is slightly longer than the Moon's orbital period.

It's difficult to measure the precession of the apsides accurately, and the Mechanism's designers assumed a value of 8.88 years. To implement this so-called precession of the apsides, they mounted the pin-and-slot gears for the lunar anomaly on a much bigger gear that rotated at that rate, ensuring that the Moon pointer operated according to the very latest theories. Any resulting error was due more to play in the gears than to faulty design.

The Problem with Planets

Lunar and solar anomalies are subtle. You could spend your whole life observing the Moon without noticing that its speed against the background stars varies by plus or minus 10%. The planets are another matter entirely. They actually briefly stop in their tracks and then move backward for a few weeks or months in a phenomenon called *retrograde motion*.

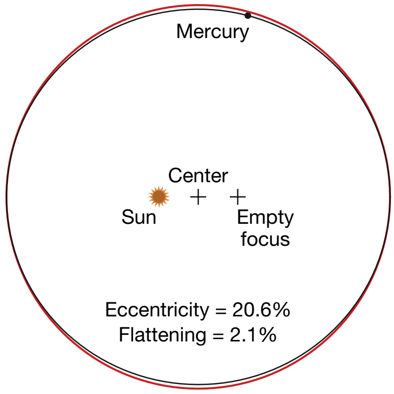
Babylonian astronomers were particularly fascinated by the planets because they were always examining celestial phenomena for abnormal behavior that could be interpreted as portents. Eclipses are the most obvious example and were often thought to portend the downfall of rulers. Planetary appearances, disappearances, and "stations" (standing still with respect to the stars) are less dramatic but also much more frequent, providing ample material for astrological forecasts.

The development around 400 BC of personal horoscopes upped the ante. Previously, astrology had applied only to countries and kings — great clients if you can find them, but in short supply. The idea that the stars actually ruled everybody's life greatly expanded the potential customer base, setting off the quest for greater accuracy.

▶ **SOLAR SYSTEM IN A BOX** This is roughly what the Antikythera Mechanism originally looked like, complete with the hypothetical front dial from the 2021 reconstruction. In addition to protecting the dials, the front and back covers contained operating instructions.

ECCENTRIC MOON ORBIT: BEATRIZ INGLESSIS / *S&T*; MULTI-SIDED VIEW OF MECHANISM: © 2021 TONY FREETH

▶ CIRCLES VERSUS ELLIPSES We now know that solar system orbits are ellipses rather than circles, with the attractor (the Sun in this case) occupying one of the foci. The critical factor is that the attractor is off-center, which is also true of the ancient Greeks' eccentric circular orbits (shown in orange). The ellipse's flattening is barely perceptible for Mercury. The two models yield essentially identical results within the error of ancient measurement.



With their penchant for patterns, Babylonian astronomers soon realized that planetary phenomena repeat in cycles (*S&T:* Aug. 2021, p. 24). For instance, they concluded early on that Venus makes roughly five morning appearances and five evening appearances every 8 years, yielding a period of 1.6 years (8/5). But with the benefit of several centuries of consistent observations, Babylonian astronomers discovered that the 1.6-year Venus cycle falls short by 19 days over the span of a century. They eventually settled on 720 cycles every 1,151 years, for an average of 1.59861 years apiece — a very close match to the modern value of 1.59865 years.

In 2016, ancient-science expert Alexander Jones was able to decipher the number 462 in the section of the Front Cover devoted to Venus. He realized that it represented an approximation previously unknown in ancient literature: 289 Venus cycles every 462 years, for 1.59862 years per cycle. It seems likely that the ancient Greeks worked this out independently.

Likewise, Jones found the number 442 in the Saturn section, yielding the previously unknown approximation 427 Saturn apparitions every 442 years, or 1.03512 years per cycle, which compares well to the modern value of 1.03514 years.

Unfortunately, the predictions can't have been all that good, because they must have been based on the assumption that a planet's retrograde loop is always of the same duration. In fact, Mars's retrograde loops vary in length from about 60 to 80 days. Implementing uniform retrograde loops would be relatively easy with a pin-and-slot mechanism, but there was neither a theoretical basis nor a practical way to implement the variations that we now know to be caused by the fact that both Earth and the planet in question have elliptical, variable-speed orbits. It would take another two centuries before Claudius Ptolemy developed models that could predict planetary motions more accurately.

The authors of the 2021 *Scientific Reports* paper offer a very clever explanation of how the mathematicians behind the Mechanism might have derived the periods for Venus and Saturn. The authors then extend those same methods to the other planets and present gear designs that could have implemented them, together with uniform-length retrograde cycles.

How and Why

The Antikythera Mechanism is so sophisticated that even to modern eyes it seems almost miraculous. Yet other, comparable devices must have existed — nobody then (or now) could build such a complex machine on their first try. Moreover, the great Roman orator and essayist Cicero (106–43 BC) described similar devices, one of which was built by his friend and teacher Posidonius and the other (or possibly two more) by the legendary genius Archimedes (c. 287–212 BC).

It may seem incredible to us today that ancient craftsmen could hand-file gears that had so many tiny teeth, but they had plenty of practice with jewelry, which requires similar levels of precision. Jones cites as other examples various medical and musical instruments, including the ancestor of the modern church organ, the water-powered hydraulis. The Mechanism's design required deep knowledge in many fields, but there were plenty of brilliant generalists in ancient Greece.

Many people have speculated about why the Mechanism was built. Two plausible explanations are that it was a rich man's plaything and that it was a device to help teach astronomy to non-experts. Those are not mutually exclusive. This was, after all, an era in which the rich and powerful were also expected to be knowledgeable about a wide range of subjects.

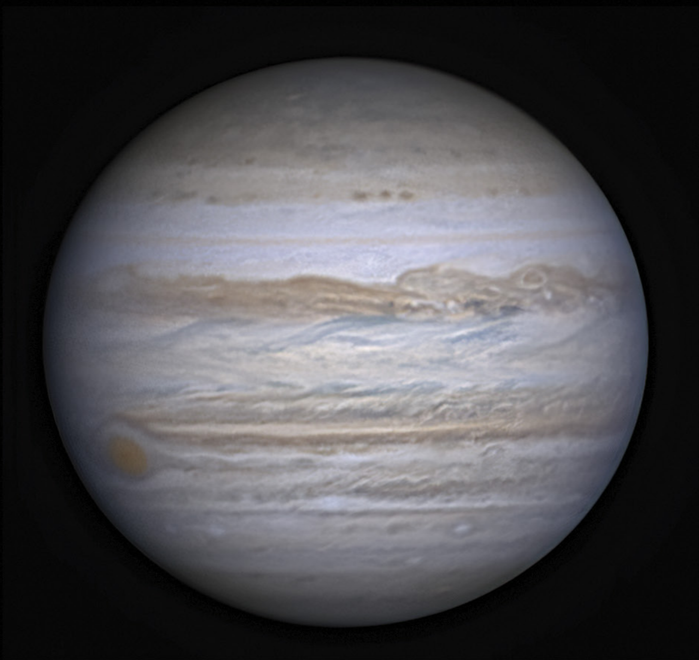
The reconstruction by Freeth and others is compatible with the educational theme. For instance, they suggest that the front dial might have had a double-headed draconic pointer showing the position of the *lines of nodes* — the intersection of Earth and Moon's orbital planes. If the saros dial on the back plate showed that an eclipse was imminent, you could then flip the device around and see the reason at a glance: Eclipses happen only when both the Sun and Moon pointers are very close to the draconic pointer.

The line of nodes rotates through the ecliptic once every 18.60 years at a nice, steady rate, so a draconic pointer would have been easy to implement. There's no evidence for it, but that's hardly surprising given that most of the instructions are illegible and the entire front half of the gearwork is missing. It would be amazing if a major new fragment was found and it confirmed the 2021 reconstruction.

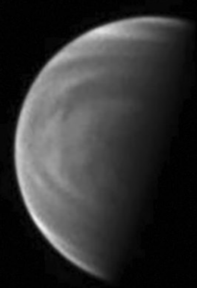
Regardless, the Antikythera Mechanism is tangible proof of the prowess of Hellenistic science, technology, engineering, and mathematics. After the 1687 publication of Isaac Newton's *Philosophiæ Naturalis Principia Mathematica*, which used mathematical techniques far more powerful than anything seen before, the phrase "clockwork universe" became a popular way to describe a cosmos that could be predicted indefinitely into the future. But it was Hellenistic astronomers who started science down that path by producing the first rigorous mathematical models of the universe at large. The fact that the ancient Greeks had the vision to embark on that journey and the genius to go as far as they did is far more important than the fact that they made a few mistakes along the way.

■ Contributing Editor **TONY FLANDERS** has been fascinated by gadgets and ancient Greece for as long as he can remember.

BEATRIZ INGLESSIS / S&T



A Planetary Imaging Primer



Here's how you can create impressive photographs of our neighboring worlds.

The planets in our solar system stand out from other night-sky objects in many important ways. At times some of them appear brighter than any of the stars, and they move noticeably. Unlike distant star clusters, nebulae, and galaxies, which appear as faint, colorless glows in most telescopes, the major planets reveal fleeting glimpses of small-scale features and distinct colors in the eyepiece.

Recording such details is perhaps easier than you think. Dust storms raging across the surface of Mars, storms in the belts of Jupiter, or tiny gaps in the rings of Saturn can be photographed by anyone with a mid-size telescope and steady skies. Here's how you do it.

Which Telescope?

Although the planets are relatively nearby, resolving details on their disks still requires a lot of magnification. Most any telescope can produce pleasing planetary images, though detecting swirling clouds within Jupiter's Great Red Spot or the Tharsis volcanoes on Mars requires an aperture of at least 8 inches.

Refractors, reflectors, and catadioptric telescopes are all available with apertures suitable for planetary imaging, but each has its own strengths and weaknesses. For example, an 8-inch apochromatic refractor theoretically provides the greatest contrast due to its unobstructed aperture, but such instruments are very expensive, relatively heavy, and feature tubes longer than many comparable reflectors.

The best-value telescope suitable for planetary imaging is the Newtonian reflector. But the design's biggest weakness is that its tube can be prone to flexure, requiring frequent collimation to ensure consistent optical performance throughout the night. Additionally, an equatorial mount can place the eyepiece of Newtonian at an awkward location as the instrument tracks across the sky.

A good compromise between aperture and portability is the popular Schmidt-Cassegrain telescope (SCT). This design utilizes a corrector plate and mirrors to fold a long optical path into a compact package, resulting in an instrument roughly one third as long as a Newtonian reflector or refractor with the same size aperture. Other Cassegrain variants such as the Classical Cassegrain or Maksutov-Cassegrain are also suitable.

Regardless of which telescope you choose, there are a few additional accessories you'll need. Resolving the smallest planetary details requires a long focal ratio, around f/20 or more. Commercial telescopes are typically offered with focal ratios of f/4.5 to f/10, so you'll need a quality Barlow lens, eyepiece projection adapter, or other amplification device (like Tele Vue's Powermates) to achieve the desired focal ratio.

Imaging with extremely long focal lengths means an electric focuser is a must-have accessory. Attempting to manually focus will simply magnify the vibrations from your hand, producing an unsteady view that is virtually impossible to focus. And you'll also be refocusing many times during the night as the temperature drops and seeing conditions change.

One other useful accessory that has gained popularity in recent years among planetary imagers is the Atmospheric Dispersion Corrector (ADC). This device resembles a short Barlow that contains two weak prisms placed in the optical path. Earth's atmosphere is loaded with water vapor, which smears light into its component colors, an effect known as *atmospheric dispersion*. The effect appears as red and blue fringing on the top and bottom of your target planet and becomes more pronounced the closer the planet is to the horizon. By adjusting the ADC, you can correct this chromatic smear and noticeably improve the sharpness of the image. An ADC is a worthwhile investment, particularly at more northerly locations where the planets arc across the sky at lower elevations.

◀ **DETAILED DISKS** Capturing planetary detail has never been easier. The author recorded this montage using a 12.5-inch Newtonian reflector with various high-speed video cameras. He captured the images from his home in southern New Hampshire — a location often assumed to be less than ideal for planetary imaging.

▶ **READY FOR ACTION** The author's 12.5-inch Newtonian reflector awaiting nightfall while aimed at the Moon. Our satellite is a great target to practice planetary imaging when the planets aren't visible.

ALL IMAGES COURTESY OF THE AUTHOR

This is most important when a planet is in the southern part of the ecliptic (as Saturn has been for the past several years).

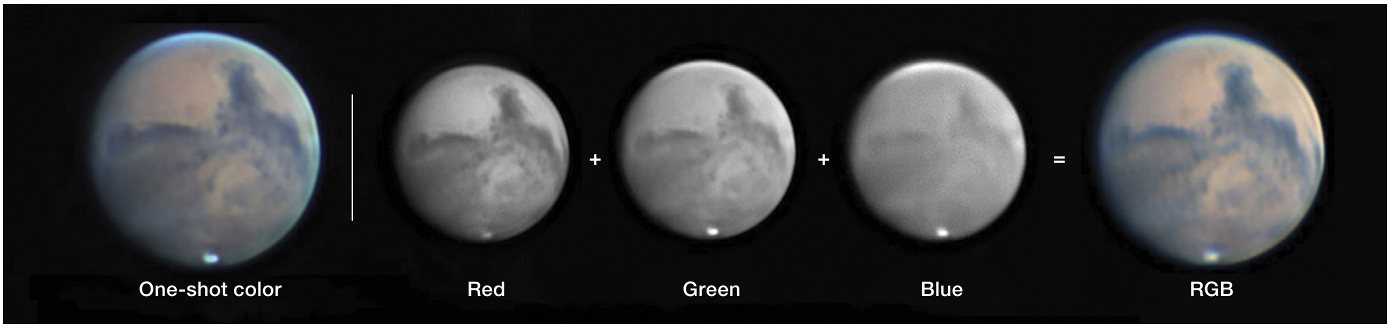
Cameras and Computers

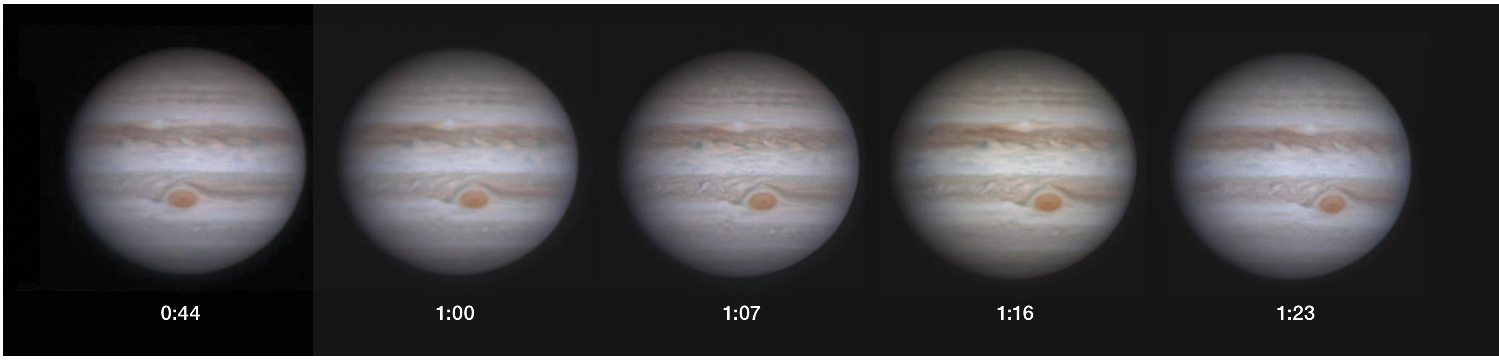
Of course, in addition to the items already discussed, planetary imaging requires a suitable camera. Unlike deep-sky objects, which require long exposures to capture, the planets are bright and only need exposures of a fraction of a second. But due to the wobbly nature of Earth's turbulent atmosphere, you're unlikely to get a single exposure that resolves a wealth of small-scale detail. Instead, planetary imaging is based around the *lucky imaging* technique, in which you record a series of exposures or a video sequence of your target, then run the data through a computer program that selects and combines the sharpest individual frames.

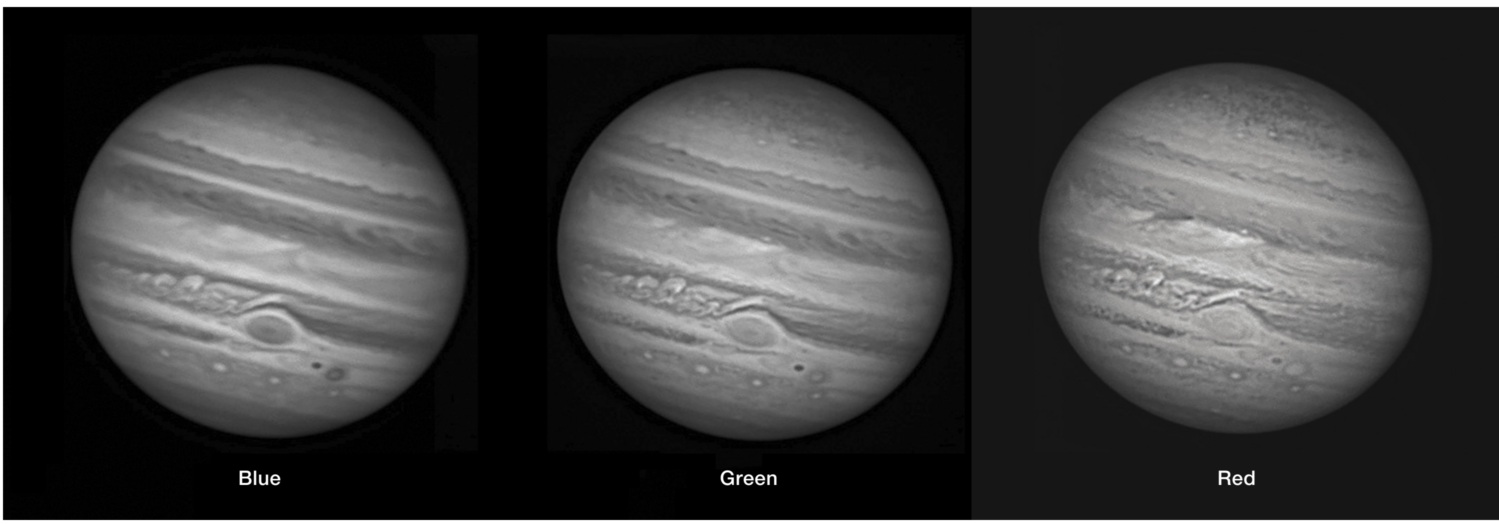
While you can use a DSLR or other digital camera to record your images, there are many specialized cameras that can record hundreds of frames per second and transfer them to your computer via a USB 3.0 or GigE connection. Such cameras typically come with their own software that permits fine-tuning your exposure, frame rate, and gain settings to achieve the best results.

These specialized cameras utilize CMOS sensors, are about the size of an eyepiece, and come in either monochrome or one-shot color formats. Color cameras are particularly good choices for beginners or those exclusively interested in capturing images of the planets in natural color. Monochrome models need the addition of a filter wheel and red, green, and blue filters in order to produce color images.

Until fairly recently, monochrome cameras used with





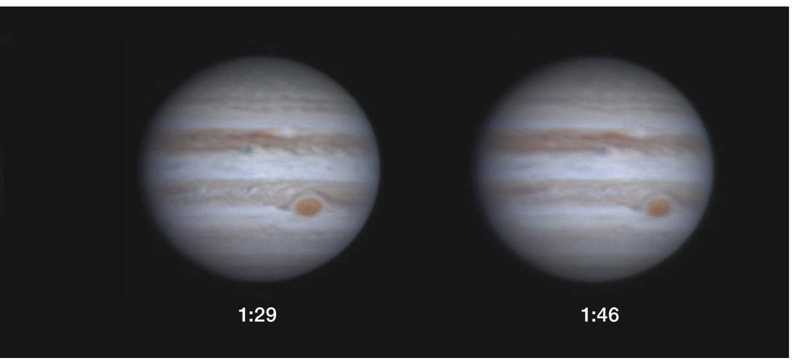


color filters produced the very highest-resolution images. That was because they didn't require a Bayer color filter array, which divides a color sensor into a grid with 50% of the pixels having green filters, 25% blue, and 25% red. This grid produces inherently lower resolution than a monochrome camera using separate color filters. But improvements in the interpolation algorithm (known as *debayering*) have made the difference negligible. If you're simply interested in taking great color images of the planets, then a color camera is the best path to follow.

Still, monochrome cameras are more versatile, particularly if you're interested in imaging wavelengths that lie outside the visible spectrum, such as ultraviolet, near infrared, and the methane band that reveals details deep within Jupiter's atmosphere.

Planetary cameras record video in AVI or SER formats, and most have the option of creating individual FIT or PNG files. Be aware that these cameras can produce a massive amount of data — it's not uncommon to collect several hundred gigabytes of image data in an evening, requiring a computer with a substantial hard drive and a fast write speed. When shopping for a computer, look for one with USB 3.0 ports and a high-capacity solid-state drive (SSD), as these are capable of write speeds of hundreds of megabytes per second. Avoid budget models that rely on cloud storage, as it's simply too much data to pass through an internet connection, particularly over Wi-Fi. If you're using an older laptop or one with a slower write speed, all is not lost — some manufacturers have begun adding on-board DDR3 memory buffers to newer camera models, which can help prevent dropping frames when operating the camera with slower computers.

◀ **COLOR OR MONO** This comparison shows Mars recorded with a one-shot color camera (far left) under fair seeing conditions compared to a series taken with a monochrome camera with individual RGB filters captured immediately afterward. Can you see much difference?



▼ **PATIENCE PAYS OFF** Conditions can change throughout the night, so it pays to be patient. This series of Jupiter images shows how the seeing can ebb and flow over the course of one hour.

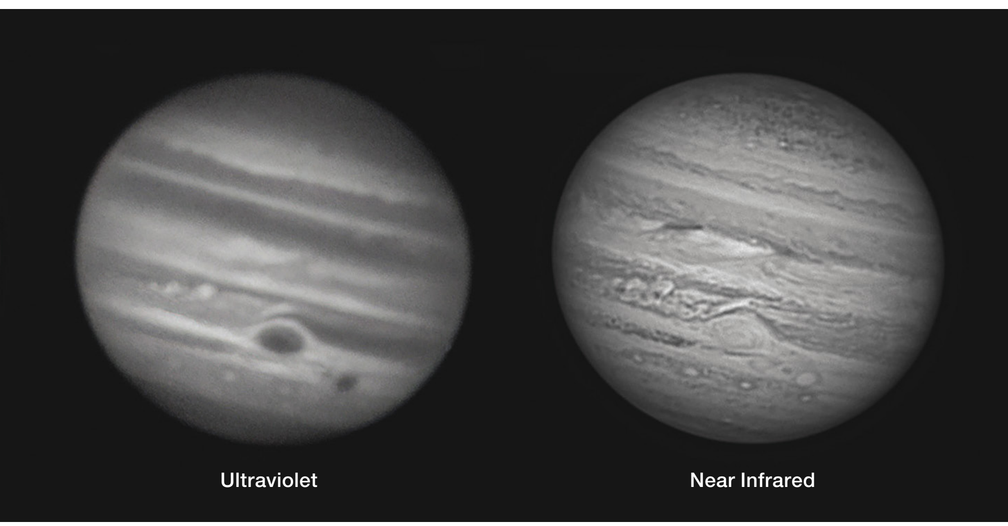
Even then, you'll also want to pick up a large portable drive to back up your videos or image files and move them to your main processing computer.

While your camera may have come with its own control software, there are programs designed specifically for planetary imaging that feature additional capabilities, including controls for electronic focusers and filter wheels. Some also allow you to pre-program the exposure length and gain settings for each filter. *SharpCap* (**sharpcap.co.uk**) for PCs supports a large array of camera models. Both PC and Mac users can operate their cameras and accessories with *FireCapture* (**firecapture.de**), which is perhaps the most popular and versatile program for capturing planetary data. There's also *AstroImager* (**cloudmakers.eu/astroimager**) for Macs.

In the Field

With your equipment assembled for a night of imaging, you need to address a few crucial considerations before recording your first frames.

Possibly the most critical step is to ensure your telescope is in perfect collimation. Because you're imaging at a long focal length, even a slight misalignment in your optics will significantly reduce the quality of your images. You should check collimation before starting an imaging run, using a bright star in the same region of the sky as your target planet. It's also advisable to check collimation frequently throughout the night.



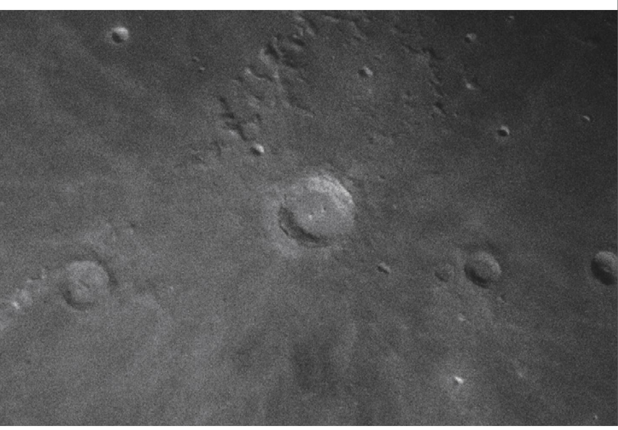
◀ **MULTIPLE WAVELENGTHS** A monochrome camera equipped with color filters isolates individual wavelengths of light, which is particularly desirable for imaging beyond the visible spectrum. This permits accurate measurements of the intensity of transient features visible in the target planet, such as the large storms seen in Jupiter's belts and zones.

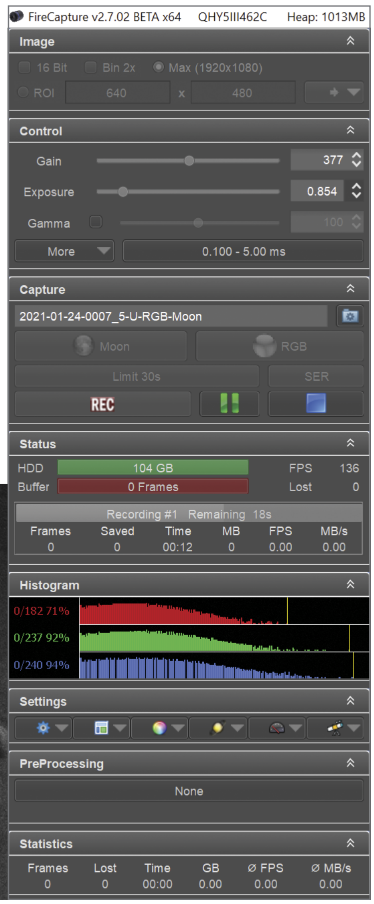
Another important step is to give the telescope ample time to reach thermal equilibrium. If your telescope is warmer than the surrounding air, it will radiate heat, which will blur the image. Give your telescope about an hour to cool before starting to image. The process can be sped up with the use of fans or more exotic active-cooling devices.

The biggest limiting factor in the quality of your images will be the atmospheric seeing conditions above you. It's best to monitor weather conditions using websites that cater to astronomers, such as **astrospheric.com** or **meteoblue.com** to see if it's worth setting up your telescope at all.

With these preliminaries out of the way, there's one more critical step you need to perform before hitting the record button: Focus the camera. Achieving perfect focus is pretty easy under steady seeing conditions. More likely, you'll end up racking the focuser back and forth trying to find a good approximation of focus on a less-than-optimal night. While some control programs include a focusing aid, I find it more reliable to focus by eye using a high-contrast area on my target such as a moon's shadow on the cloudtops of Jupiter, or the Cassini division in Saturn's rings. It may take several minutes of trial and error to achieve sharp focus, but take as long as you need. I often refocus frequently throughout the night as the temperature and seeing conditions change.

At last, you're ready to record! As you image throughout the night, keep in mind that your target is a rotating planet. That means there's an upper limit on how long you can image before that rotation begins to smear the fine details you're trying to capture. For example, Jupiter rotates quickly, so I limit my videos of it to 1 minute or less when the seeing conditions are excellent. Saturn is noticeably smaller and fainter, and I can go about 90 seconds or so before its rotation begins to affect image quality. With Mars, the limit is closer to 3 minutes. Neither Venus nor Mercury rotates fast, so you can record longer videos of each, though you'll still want to keep an eye on your file sizes.





▼▶ **COMPLETE CONTROL** Specialized camera-control software such as *FireCapture* (**firecapture.de**), seen at right, allows more options than most software that comes with a camera. Both *FireCapture* and *SharpCap* (**sharpcap.co.uk**) offer additional control of electric focusers and filter wheels.

Planetary Processing

Once you've recorded and copied your data off the control computer, it's time to stack and process your data. There are several programs that can accomplish this, including *AutoStakkert! 3* (**autostakkert.com**), *AstroSurface* (**astrosurface.com**), and *RegiStax 6* (**astronomie.be/registax**). Each one will distill your video or image files into an image suitable for additional processing steps, such as sharpening. Mac users also have several options, including *Lynkeos* (**lynkeos.sourceforge.io**) and *Planetary System Stacker* (**https://is.gd/PlanetarySS**).

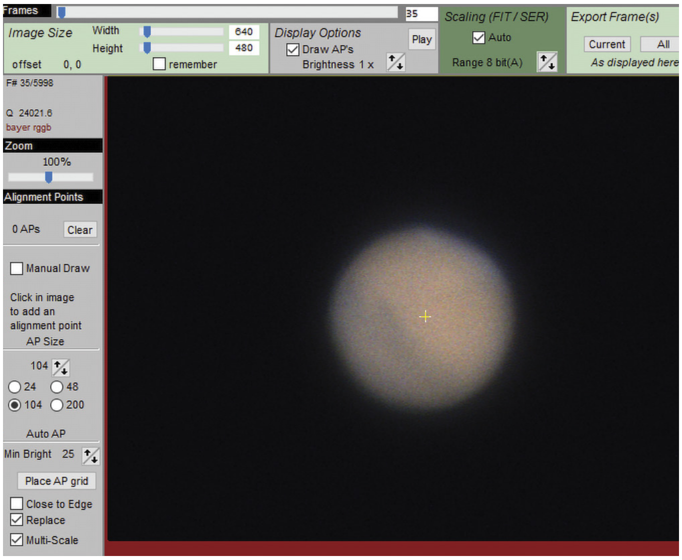
While *AutoStakkert! 3* includes a rudimentary sharpening feature, its writer suggests that other planetary-imaging software offers better options. I prefer to stack my video files in *AutoStakkert! 3* and then bring the stacked image into *WaveSharp* (**https://is.gd/WaveSharp**) to utilize its powerful wavelets sharpening tool. (*WaveSharp* is the successor to *RegiStax 6* currently in development, though it only includes sharpening tools and does not stack images.)

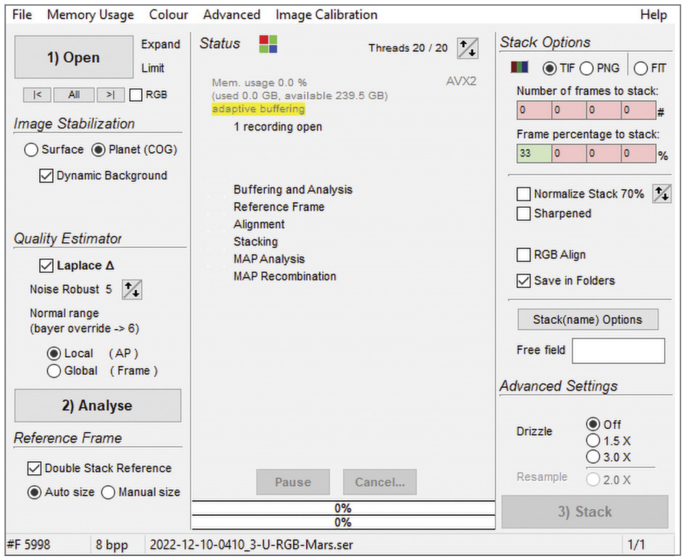
Both *RegiStax 6* and *Autostakkert! 3* offer two ways to stack your images. There's *single-point alignment*, which is most useful for planets when they're only a few arcseconds across, such as Uranus and Neptune, or Mercury, Venus, and Mars when they're far from Earth.

The second stacking option is *multi-point alignment*, which lets you select dozens of points to align and stack on. This works best on close-ups of lunar craters, on Jupiter and Saturn, and on Mars, Mercury, and Venus when their disks are large.

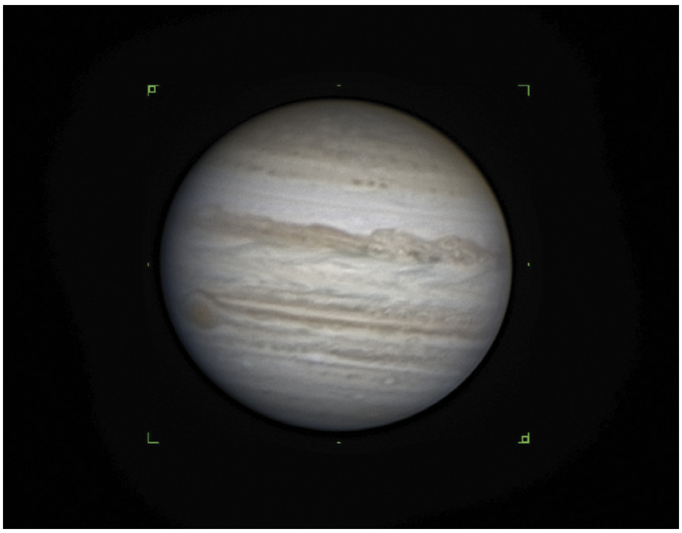
All stacking programs function in a similar fashion: They first evaluate and order the frames, then you choose how many to include in that stack. Generally, the more frames you stack, the better the signal-to-noise ratio is in the resulting image, allowing you to aggressively sharpen it. How many frames you stack will vary depending on the seeing conditions. When the seeing is steady, you might be able to use half the frames you've acquired, but when conditions are poor perhaps only 20% of your frames will make the cut. Adding more frames to a stack taken under poor seeing will only produce a blurry result. If you're unsure of how many to stack, *AutoStakkert! 3* permits you to create up to 8 custom stacks at a time so you don't have to go back and redo the lengthy process.

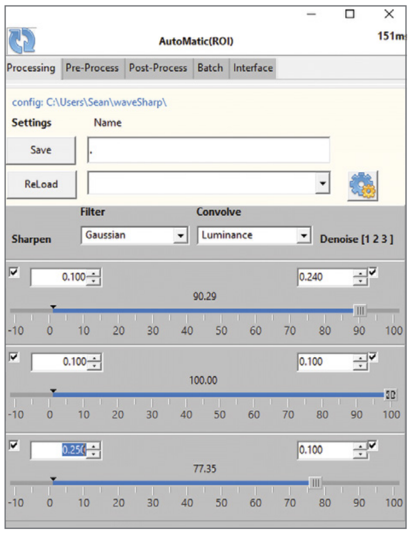
With your data all stacked, it's time to sharpen the results. I prefer using the





▲ **AUTOMATIC STACKING** *Autostakkert! 3* is a free program that performs multi-point stacking of videos or individual frames and requires very little user input.





◀ **WAVELET SHARPENING** *WaveSharp*, the successor to the popular stacking program *RegiStax*, contains powerful tools that permit both sharpening and noise control.

Wavelets tool in *WaveSharp*. The three control sliders generally correspond to fine, medium, and course detail. I suggest experimenting with the values of each slider to find a combination that works best for your image. You can also save your wavelet settings and build a library that works with a wide range of conditions.

There's an additional way that seasoned planetary imagers use to improve their images even more. The technique of *de-rotation* is a powerful feature built into the freeware program *WinJUPOS*. It allows you to combine many stacked images taken over a long period of time to reduce noise and further improve detail. A tutorial on the technique can be found in the May 2013 issue, page 70.

More than Pretty Pictures

Your planetary photos can be more than just nice, sharp pictures to post on social media. The images you produce may be of interest to professional astronomers, who cannot monitor the planets on a full-time basis. They rely on networks of dedicated amateurs through groups such as the British Astronomical Association (**britastro.org**), the Association of Lunar and Planetary Observers (**alpo-astronomy.org**), the International Society of Mars Observers (**https://is.gd/des4ml**), and ALPO Japan (**alpo-j.sakura.ne.jp/indexE.htm**). These groups welcome new members and together provide almost continuous monitoring of the major planets.

The amount of detail you can capture on nearby worlds from your backyard is truly amazing. And with Jupiter reaching opposition this month and Saturn well-placed in the evening sky, it's a great time to get involved yourself.

■ Associate Editor **SEAN WALKER** focuses on imaging and observing the Sun, Moon, and planets from Dunkelheit Observatory in southern New Hampshire.

 by Jennifer Hanley

The Salty Solar System

These common compounds could determine whether life can find a foothold on other worlds.

When we look for places across the solar system where life could survive, either now or in the past, NASA's motto has been "follow the water." But conditions on other planetary bodies are not ideal for pure liquid water to exist — the temperatures are too cold, the atmosphere is too thin, or both. Earth is the only world where pure liquid water is stable on the surface and can transform easily between ice, liquid, and gas phases. In order for liquid water to exist at the temperatures and pressures seen on the surfaces of other solar system bodies, something must lower the freezing point. That something is salt.

Salts are a vital part of our world, and how they interact with water (which is essential for life as we know it) can affect habitability. Different salts affect water in different ways, changing the temperatures at which water freezes and boils. This is why we salt roads in the winter in cold climates: The salt lowers ice's melting temperature, keeping water from freezing on the asphalt. Even our bodies need a certain amount of salt in order to do things like conduct nerve impulses and regulate fluids. But too much can be toxic. This is why we cure foods like meat with salt — salt leeches water from bacterial cells and prevents their growth.

We find salts beyond Earth, too. Salts appear in places where liquid water has interacted with rocks in the past. The water breaks down minerals in the rock and redeposits some of the elements as salts. Scientists have identified salts on numerous planetary surfaces: Mars; the dwarf planet Ceres; the Galilean moons Europa, Ganymede, and Callisto; the icy moon Enceladus; meteorites; and even in lunar samples.

If we truly want to understand water's behavior across the solar system — and the habitable environments it might or might not help create — then we need to study salts.

A Salty Mars

The salt most of us are familiar with is sodium chloride (NaCl), also known as halite or table salt. Besides water, this is the main component of Earth's oceans, around 3.5% by weight. When the ocean evaporates to form clouds, only the water evaporates, not any of the other things dissolved in it. The same is usually true for ice: Pure water ice freezes from a salty solution, concentrating the salt in the leftover liquid further. This behavior is why most lakes and rivers are "freshwater": They are replenished through rain or snow, which come from clouds. It also has implications for bodies of water we might find in extreme locations, like the Great Salt Lake, the Dead Sea, or an ocean on another planet.

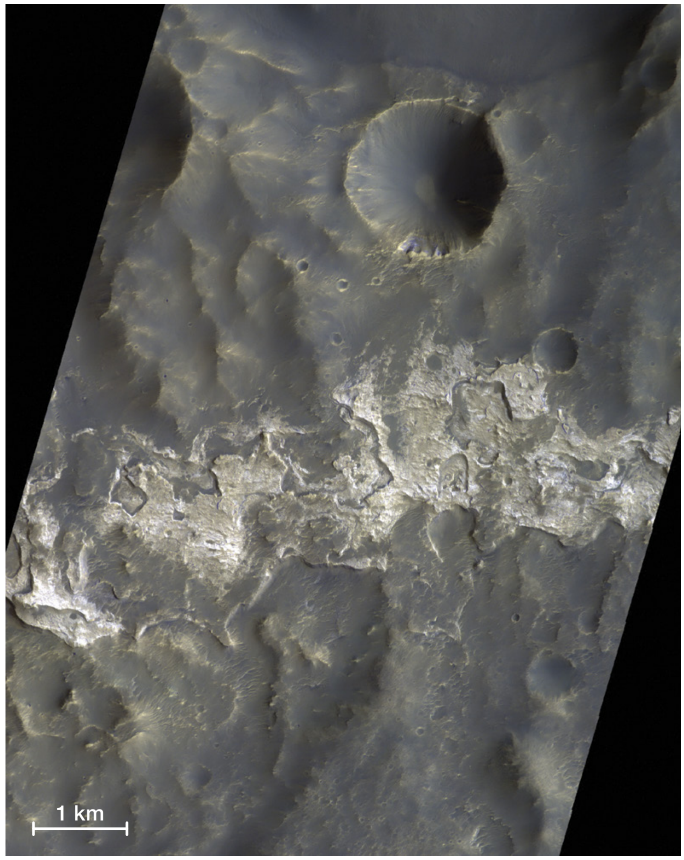
There are many different types of salts beyond halite. Salts in general consist of a positively charged cation (such as Na^+) and a negatively charged anion (such as Cl^-). Other common cations include magnesium (Mg^{2+}), potassium (K^+), calcium (Ca^{2+}), and iron (Fe^{2+} and Fe^{3+}). Common anions include sulfate (SO_4^{2-}), nitrate (NO_3^-), carbonate (CO_3^{2-}) and perchlorate (ClO_4^-). These ions dissolve separately in water, but when they precipitate out, they combine to form a salt with no net charge (e.g., NaCl).

SALT TEXTURE: DOMNITSKY / SHUTTERSTOCK.COM; SALT DEPOSIT ON CERES: NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA / PSI

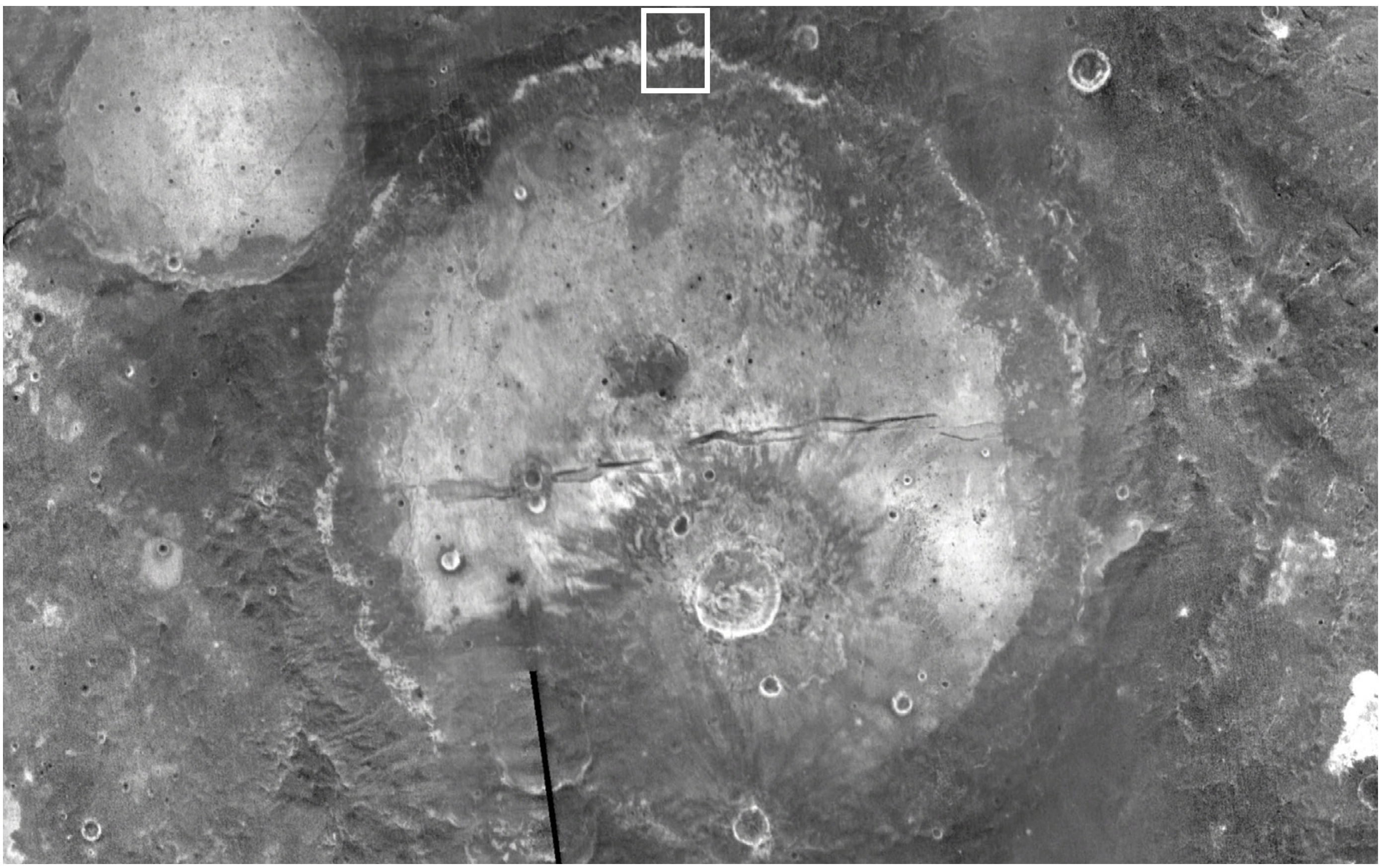
CRYOVOLCANO?
Sodium chloride and other salts appear in Cerealia Facula, the brightest spot on the dwarf planet Ceres. The highly reflective blotch covers the dome at the center of Occator Crater. The salts may be residue from brines that welled up recently — or are even still ascending — through various fractures. This mosaic combines images taken by NASA's Dawn spacecraft from different altitudes.

Different salts can dissolve at different concentrations in water before the water can't hold any more (called the *solubility limit*). Then they precipitate out of solution in a specific order. We can see this in Columbus Crater on Mars: As an ancient lake began to evaporate away, salts that had a low solubility started to precipitate out first. As more water was lost and the lake level sank, different salts continued to form a sort of salty "bathtub ring" around the crater wall. By identifying the types of salts and their formation sequence, we can understand the history of that lake, such as its salinity and which ions were dissolved in it. That in turn can tell us how long the lake took to evaporate as well as about the kinds of lifeforms that might have been able to survive there.

We also want to understand how salts affect water's behavior. One avenue of research is to test how cold water can be before it freezes. This is done through laboratory experiments and theoretical modeling. You might think "surely this has been done before," but many things can impede a confident measurement. For one, it's expensive and challenging to recreate conditions like those on the Martian



▼▶ **DRAINED TUB** This infrared image *(below)* of Mars's Columbus Crater reveals distinct materials on the crater wall and floor. The light-toned "bathtub ring" around the crater is made of hard, salty deposits, perhaps left by long-gone water. Much of the brighter materials inside the crater are lava flows, but a subset may also be salts, especially on the northeastern crater floor. The image at right is a close-up of the ring at the 12 o'clock position; the crater above the ring section is 1.6 km wide.



COLUMBUS: NASA / JPL / ARIZONA STATE UNIVERSITY; RING CLOSE-UP: ESA / ROSCOSMOS / CASSIS / CC BY-SA 3.0 IGO

surface. The surface temperature peaks at 20°C (68°F) in the summer at midday at the equator, but the *average* temperature on Mars is −65°C (−85°F). In the winter at the poles, the planet can be as chilly as −143°C (−226°F).

In addition, we have to account for the atmosphere's pressure and water-vapor content, two things that will affect the stability of liquid water. On Earth, pure water boils at 100°C at sea level. However, at higher altitudes, such as Flagstaff's 7,000 feet in Arizona, the atmospheric pressure is lower, and water boils more readily. This means you only need to heat your water to 93°C to boil it. This is why there are such things as high-altitude cookbooks — because water behaves differently there!

On Mars, the atmospheric pressure is less than 1% Earth's, so pure water would boil at about 10°C. It freezes around 0°C. This does not give us much room to work with if we want to find liquid water that won't boil and is above freezing. However, by adding salt, which inhibits the water molecules from interacting with one another, we slow down the processes of boiling, evaporation, and even freezing. For instance, if we add magnesium perchlorate to our water on Mars, we can lower the freezing point to at least −67°C and increase the boiling point to 24°C.

Just Add Salt

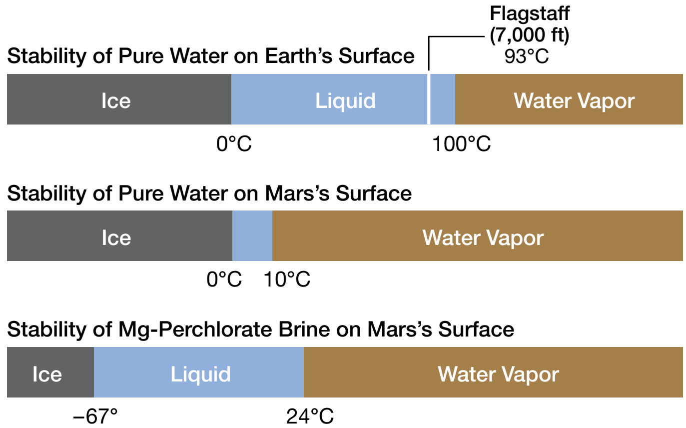
Another interesting interaction between salt and water is the process of *deliquescence*. Deliquescence is when salts pull in water molecules from the atmosphere, dissolve, and form a liquid. This process enables liquid water to exist stably at temperatures and pressures that would otherwise be too low for water's condensation. On Earth, deliquescence happens both naturally and due to human activities; we use it in applications like industrial drying or as a method to control humidity in specific environments.

We see deliquescence in the driest regions on Earth, such as the Atacama Desert in Chile. This location serves as an analog site for Mars because it is exceptionally dry, shielded by the rain shadows of two mountain ranges. On average in an entire year, it only precipitates a few millimeters, mostly in the form of fog or dew. It is so dry that most life cannot exist there, as liquid water is important for nutrient transport within organisms. The life we do find is primarily photosynthetic, taking its energy from the Sun. But because cell activity can only occur with liquid water and sunlight, life mostly exists in an inactive mode to withstand desiccation.

Salt comes to life's rescue. Halite crusts occur across the region, pulled from the desert rocks by wind erosion and formed by the partial dissolution and reprecipitation of salts during the rare times it is wet. Microorganisms live among the salt crystals in these shallow crusts, which deliquesce at lower humidity than that at which pure water condenses. A 2008 study found that in one year, water condensed 57 times in the halite crusts, versus only once in the surrounding dirt. That increased the time available for possible photosynthetic activity by more than a factor of 30.

LEAH TISCIONE / S&T

Water's Behavior on Earth and Mars



This process could be happening on Mars today, especially in the polar regions. NASA's Phoenix mission to the north pole of Mars discovered perchlorate salts, which are especially prone to deliquescence. In the summer there water ice sublimates, providing a source of water vapor along with the warmer temperatures needed for deliquescence to occur. The resulting brine droplets would be stable for several hours at a time, potentially allowing life the rare opportunity for cell activity. We might have seen such brine droplets on the legs of the Phoenix lander after it touched down in 2008.

Salts in the Belt and Beyond

Salts on Mars are likely evaporite deposits, either from upwelling groundwater or lake drainage, and are not being created in great quantities today. But elsewhere in the solar system, we find a different situation.

One place in the solar system where we find lots of salt is Jupiter's moon Europa. Europa is about the size of our moon but covered in a water-ice crust. The lack of craters indicates that the surface is relatively young in geologic terms, between 20 to 180 million years old, meaning something must have resurfaced it recently. Various lines of evidence suggest there's a subsurface ocean, which might provide the necessary material. Induced magnetic fields measured by NASA's Galileo spacecraft indicate the ocean is salty.

Europa's salts may be created by interactions between the icy surface and the ocean below it. So-called chaos regions on the surface look almost like icebergs that have broken away and then refrozen in a new orientation. These chaos regions align with where we've detected higher concentrations of salt on Europa.

Many of the salts identified on Europa's trailing hemisphere appear to be magnesium sulfates. One possible source for the sulfur is the nearby moon Io. Jupiter's magnetic field could pick up sulfur ions from Io's volcanoes and deposit them on this part of Europa's surface, where they could collide with magnesium and form the salt.

However, we still need a source for the magnesium, as well as for sodium and chloride, which we've also detected. A

possible source is water's interaction with the rocky mantle at the bottom of the ocean, perhaps even hydrothermal vents similar to the ones on Earth. On our world, these vents are a source of heat, energy, and nutrients that teem with life in the cold, dark depths of the ocean floor. Life might have even originated there.

Identifying which salts are present on Europa, and in what proportions, is shedding light on the moon's interior. A predominantly chloride ocean would have a lower freezing temperature than one with sulfates. However, this would also mean that the water-ice crust would be thicker and impede possible interactions between the surface and the ocean.

Enceladus is another moon, this time of Saturn, that has subsurface salty liquid water. Enceladus is covered in water ice as well. But with almost no impurities, the ice reflects all the sunlight that hits it, making the moon the most reflective body in the solar system. Cryovolcanoes at Enceladus's southern pole spew water and salt; while some falls back on the surface, much of it leaves the moon to create Saturn's broad and diffuse E ring.

Finding salt in the plumes tells us salt likely plays a role in preserving the liquid-water reservoir under the surface by depressing the freezing temperature. The salts probably come from water's contact with the warm, rocky mantle below. Since this mantle is squeezed and stretched by Saturn's tidal forces, that interaction might occur via hydrothermal vents. As with Europa, salts on Enceladus might not only enable habitable environments but also help us find them.

Surprisingly, we even have found salts on the dwarf planet Ceres, which is the largest body in the asteroid belt. Evidence from NASA's Dawn mission, which studied Ceres from 2015 to 2018, suggests that a cryovolcano erupted liquid water containing various salts onto the surface. After evaporation, the water left behind sodium chloride, sodium carbonate, and

magnesium sulfate. There are also many bright spots across Ceres, the salty residue of subsurface brines that welled up and evaporated. This all suggests Ceres was once, if not still, an ocean world worthy of more study.

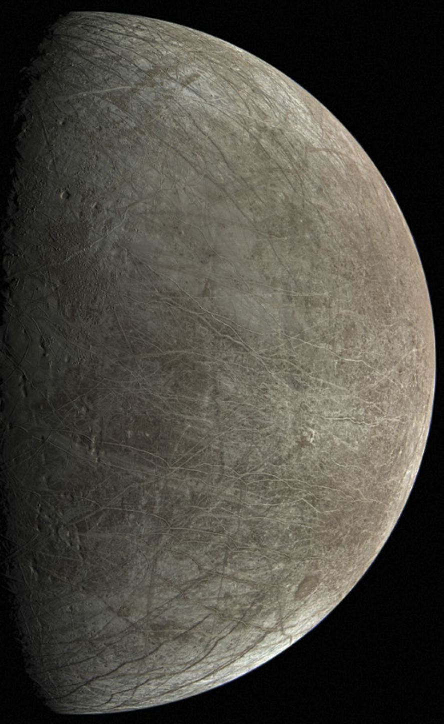
The detection of salts on all of these icy bodies (Europa, Enceladus, and Ceres) suggests they have come from the near-subsurface. Understanding the processes by which this happens is difficult. Whereas on Mars (and possibly Ceres), salts are likely evaporite deposits from groundwater upwelling or lake drainage, on the icy moons cryovolcanism likely plays the dominant role (*S&T:* Aug. 2020, p. 32). The structure of salts formed through rapid freezing — such as when a geyser erupts into the vacuum of space — is vastly different from that created by slow evaporation. While slow evaporation or freezing results in more crystalline structures, flash freezing is likely to form a glass. This would be favorable to any organisms in the liquid: The rapid drop in temperature and the lack of crystal structure would protect the cells from bursting, potentially making finding life in those conditions easier if we send the right instruments.

Follow the Salt?

While salts can be toxic to most life, some organisms have grown to tolerate salts in exchange for more opportunities to

▼ **STRANGE HABITAT** The Salar Grande in Chile's Atacama Desert is a vast salt flat that covers approximately 200 km^2. The knobby halite crusts are tens of centimeters thick, and communities of microorganisms shelter within, benefiting from the water that the salt pulls from the atmosphere.

ALFONSO DAVILA (2)



Spectral Search

We usually locate salts on other worlds through remote sensing. Spacecraft or Earth-based telescopes measure the amount of reflected sunlight from the surface, and then we look for the spectral fingerprints of various salts. Collecting laboratory spectra of mixtures is also important, because research shows that certain salts (such as gypsum) can overwhelm the signal and make identification of other salts tricky.

Salts are also impacted by the harsh radiation environment on worlds with little to no atmosphere. With laboratory experiments, we try to determine how salts, ice, and their mixtures react to different types of radiation, and how that changes their stability and spectral features.

◀ **SALT-ENCRUSTED WORLD** This enhanced-color image from NASA's Juno spacecraft shows the rugged, fractured surface of Jupiter's moon Europa. Spectral observations have revealed salts across the moon's surface, especially in jumbled, geologically young areas called chaos regions.

interact with liquid water. Unfortunately, life as we know it has a harder time utilizing a very salty brine. (Interestingly, much of the work to understand life in very salty water conditions has been done by the food industry, which wants to find ways to inhibit microbial growth in foods.) Thus we have this tension in the scientific community between wanting to find liquid water and making sure that water is habitable.

In any case, we are very unlikely to find liquid water on other worlds without salt. So perhaps our new strategy should be "follow the salt?" Many current and future missions plan to do just this. NASA's Perseverance mission is caching samples on Mars that will eventually be returned to Earth. The samples being collected are primarily those that indicate interactions with liquid water in the past, which often includes salts.

Then there are two spacecraft on their way to the Jupiter system: ESA's Juice mission, arriving in 2031, and NASA's Europa Clipper, launching in late 2024 and arriving in 2030. Juice will investigate Europa while in Jupiter orbit before eventually circling Ganymede — the largest moon in the solar system, which also has a subsurface salty water ocean. Europa Clipper will perform numerous close flybys of Europa with enhanced cameras, spectrometers, and a magnetometer to vastly increase our understanding of this fascinating moon (*S&T:* Apr. 2022, p. 14).

Scientists also have their eyes on the other salty ice worlds as they consider potential missions. Researchers have proposed that NASA send a spacecraft to Enceladus to sample its plumes in our effort to understand the internal ocean, whether and how there is any interaction between the ocean and the surface, and the ocean's potential habitability.

Another proposed mission would return samples from Ceres, which would collect a small amount of exposed salt and return it to Earth. The type of salt we've seen — primarily sodium carbonate — means there is both carbon and oxygen on the dwarf planet, a marker for habitability. Returning samples to Earth is more cost-effective than in situ measurements due to the low gravity and our close proximity to Ceres. Laboratories will be able to use state-of-the-art instruments to understand the composition of the samples and how friendly Ceres might be to life.

All of these targets have been picked due to the astrobiological implications from finding salts and water on them. Hardy microorganisms have been found in places like Antarctica and the Atacama Desert that can tolerate high salt concentrations and/or cold temperatures and/or low water amounts. But when we add all these extreme conditions together, we don't know of any life as of yet that could thrive on another planet. Work continues in the astrobiology community to understand the limits of living organisms. For now, we can better appreciate just how special Earth is — a blue temperate world with a dash of salt.

■ **JENNIFER HANLEY** is a planetary scientist at Lowell Observatory in Flagstaff, Arizona. She loves exploring the outdoors, especially with her family.

IMAGE DATA: NASA / JPL-CALTECH / SWRI / MSSS, IMAGE PROCESSING: BJÖRN JÓNSSON / CC BY-NC-SA 2.0

OBSERVING
November 2023

1 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:12 p.m. EDT (see page 50).

2 EVENING: Face east-northeast to see the waning gibbous Moon rise alongside Gemini's bright lights, Castor and Pollux. The trio is arranged in a pleasing triangle, with the Moon placed a bit less than 6° right of the stars — that distance decreases as the night progresses. Turn to page 46 for more on this and other events listed here.

4 EVENING: Algol shines at minimum brightness for roughly two hours centered at 7:01 p.m. EDT.

5 DAYLIGHT-SAVING TIME ENDS at 2 a.m. for much of the U.S. and Canada.

6 DAWN: The waning crescent Moon is in Leo, some 5° above Regulus, while Venus blazes lower left of the pair. Look southeast to take in this sight.

9 MORNING: Night owls will be greeted by the sight of the lunar crescent and Venus rising with a mere ½° between them. Most of Europe and the Middle East as well as parts of northern Africa will witness a daytime occultation.

11 DAWN: The thin crescent Moon follows Spica by about 3° as they clear the east-southeastern horizon before sunrise.

18 MORNING: The Leonid meteor shower is predicted to peak. The waxing crescent Moon sets in the early evening and won't interfere with the viewing of this usually modest show. Page 49 has more information.

20 DUSK: Face south-southeast after sunset to see the first-quarter Moon gleaming about 5° below left of Saturn. Watch the pair become more conspicuous as twilight deepens.

21 EVENING: Algol shines at minimum brightness for roughly two hours centered at 7:55 p.m. PST (10:55 p.m. EST).

24 EVENING: Algol shines at minimum brightness for roughly two hours centered at 7:44 p.m. EST.

25 MORNING: The waxing gibbous Moon and Jupiter adorn the western horizon with some 2° between them.

26 EVENING: High above the southeastern horizon the almost-full Moon shines about 1° below the Pleiades in Taurus. Binoculars will let you see the cluster stars next to the dazzle of the Moon.

29 MORNING: Venus rises in tandem with Spica, Virgo's brightest star, with a bit more than 4° separating them. Face east-southeast to catch this sight.

30 EVENING: The waning gibbous Moon, Pollux, and Castor climb above the east-northeastern horizon in a line. The Moon is less than 2° below right of Pollux.

—DIANA HANNIKAINEN

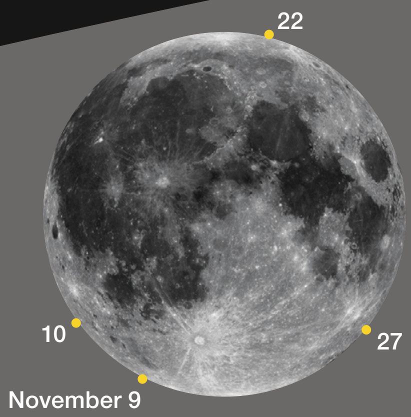
▲ Hundreds of bright, newly born stars illuminate NGC 604 in the Triangulum Galaxy (M33) in this composite Hubble Space Telescope and Chandra X-ray image. See the article on page 58 for more on this delightful object.

X-RAY: NASA / CXC / CFA / R. TUELLMAN ET AL.; OPTICAL: NASA / AURA / STSCI / J. SCHMIDT

NOVEMBER 2023 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart



Yellow dots indicate which part of the Moon's limb is tipped the most toward Earth by libration.

NASA / LRO

MOON PHASES

SUN	MON	TUE	WED	THU	FRI	SAT
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

LAST QUARTER

November 5
08:37 UT

NEW MOON

November 13
09:27 UT

FIRST QUARTER

November 20
10:50 UT

FULL MOON

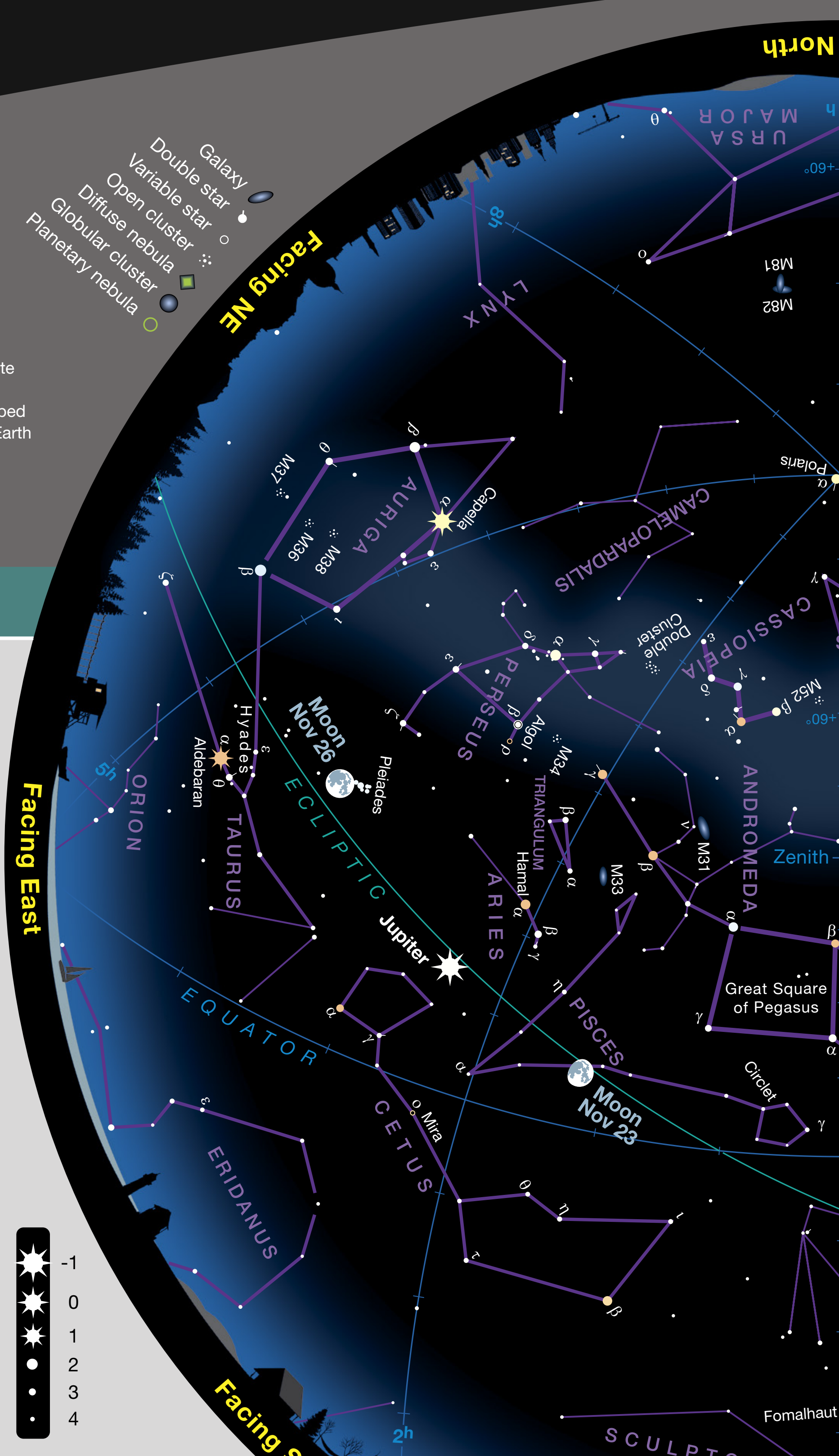
November 27
09:16 UT

DISTANCES

Apogee	November 6, 22^{h} UT
404,569 km	Diameter 29′ 32″
Perigee	November 21, 21^{h} UT
369,818 km	Diameter 32′ 19″

FAVORABLE LIBRATIONS

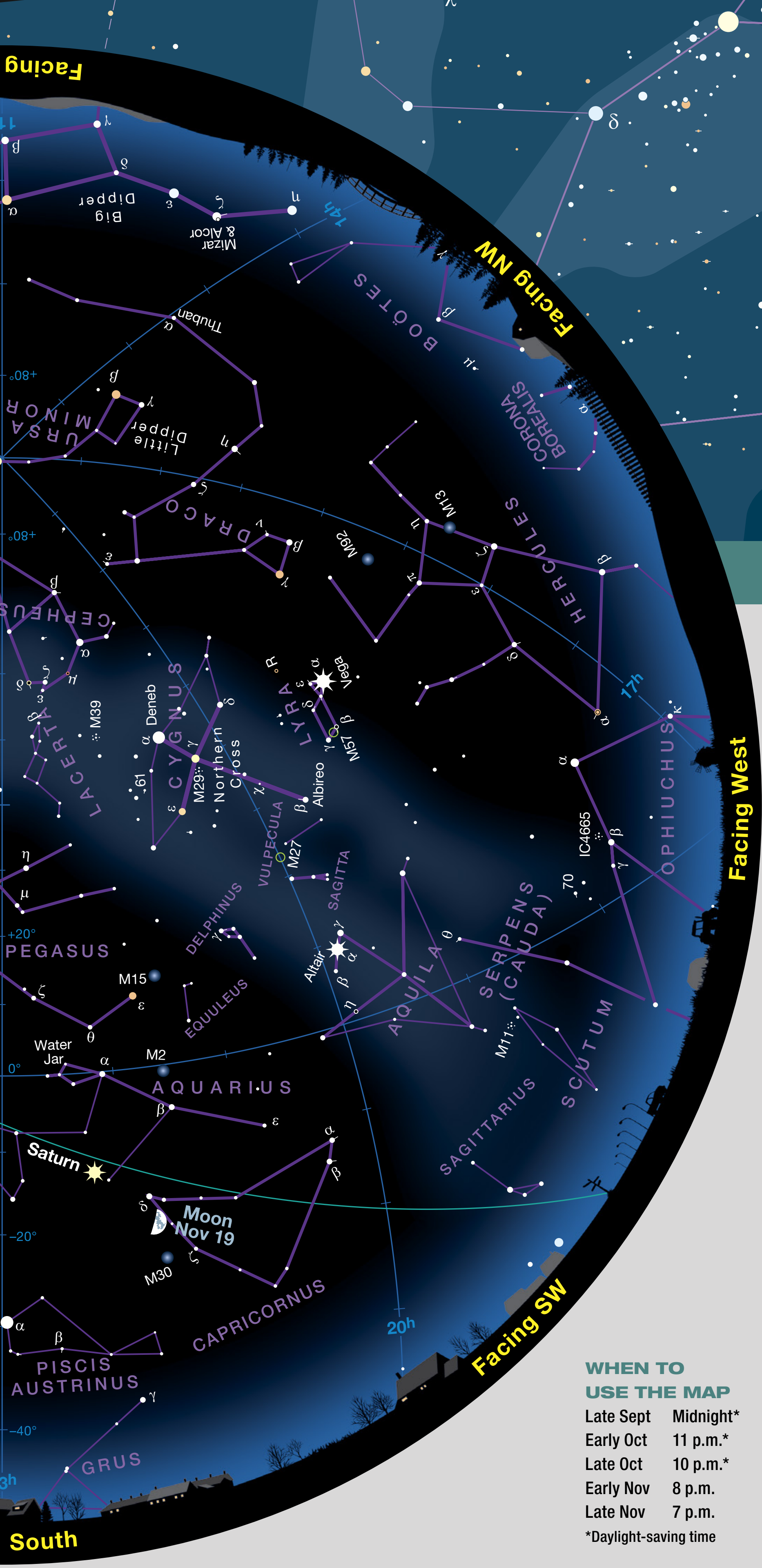
• Bailly Crater	November 9
• Lagrange Crater	November 10
• Baillaud Crater	November 22
• Harlan Crater	November 27

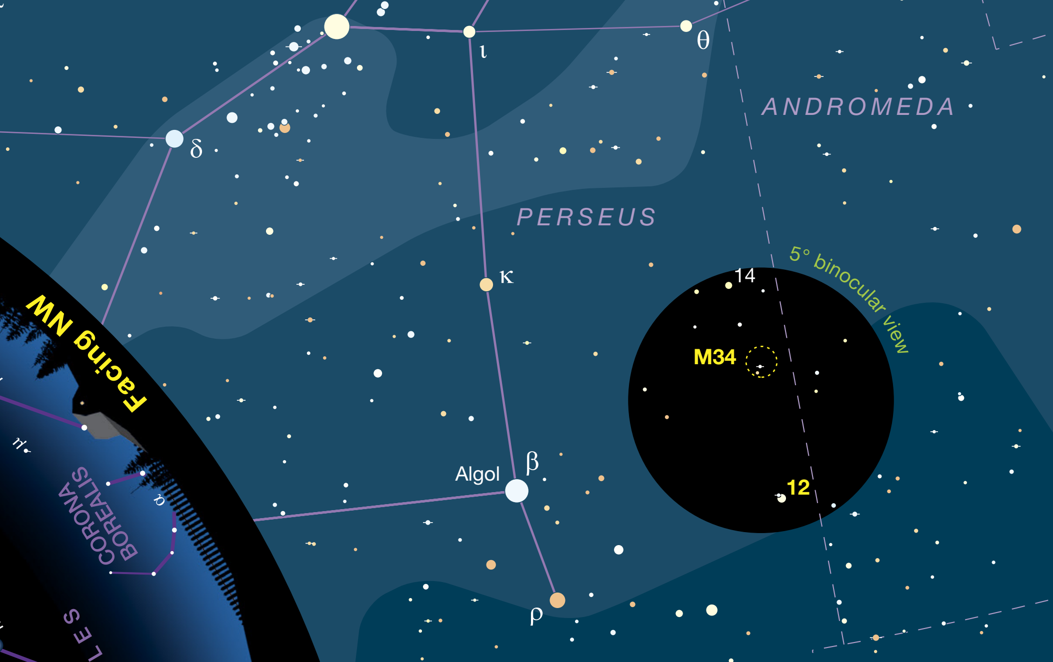


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing. Exact for latitude 40°N.





Binocular Highlight by Mathew Wedel

A Stronghold in the Sky

I bought my first telescope in the fall of 2007, and autumn has been my favorite season for stargazing ever since. Cassiopeia and Perseus, the mythical Seated Queen and monster-slaying Hero, were the first constellations I learned, and it's reassuring to see them soaring up the eastern sky, welcoming me back to my old cosmic stomping grounds.

Our target this month is the open cluster **M34**, on the western border of Perseus. With a visual magnitude of 5.2, it's naked-eye visible as long as there's not too much light pollution. As with most celestial objects, the trick is knowing exactly where to look. Find a slanted square, roughly 4° on a side, formed by Beta (β; also known as Algol), Kappa (κ), 14, and 12 Persei. M34 lies on the western edge of the box, a little north of the midpoint connecting 14 and 12 Persei. Of course, to the naked eye the cluster appears as a fuzzy star, but binoculars will reveal a wealth of detail. Look for a compact, boxy core surrounded by a ragged outer loop of eight or so 8th- to 10th-magnitude stars.

I envision the cluster as a medieval city, ringed by a strong defensive wall. The illusion of a dark moat between the core and the loop is most pronounced in 7× binos, whereas 15×70s may fill the gap with a dusting of faint suns, at least under very good conditions. M34 is on the small side as open clusters go, just some 12 light-years in diameter. But it's also fairly close, only about 1,700 light-years from our solar system, which is why it appears quite large in binoculars.

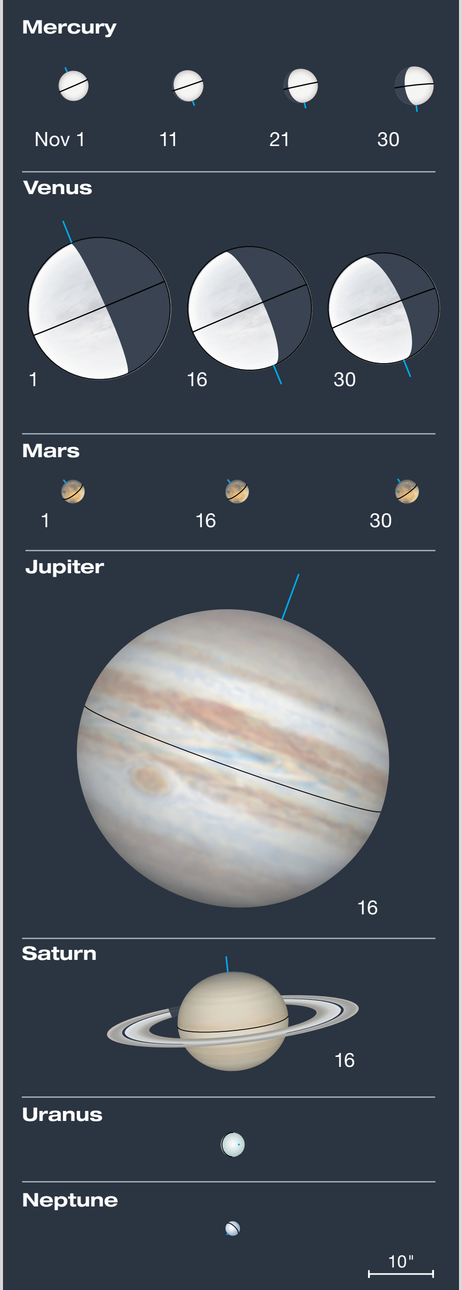
While you're in the neighborhood, check in on **12 Persei**. The 5th-magnitude primary has an 8th-magnitude companion separated by a generous 270″, making this a lovely, unequal binocular double.

■ **MATT WEDEL** was overjoyed exploring Perseus the first time, on his own, and sharing it is even better.

WHEN TO USE THE MAP

Late Sept	Midnight*
Early Oct	11 p.m.*
Late Oct	10 p.m.*
Early Nov	8 p.m.
Late Nov	7 p.m.

*Daylight-saving time



▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

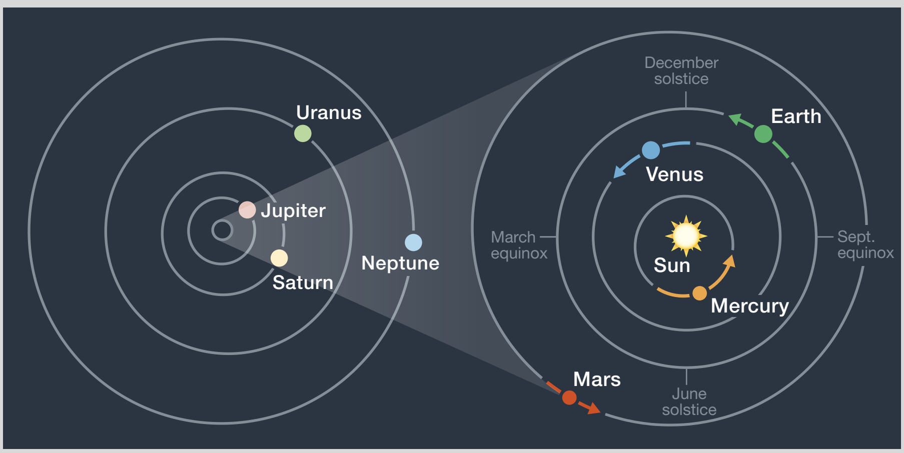
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during November. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk starting on the 26th • **Venus** visible at dawn all month • **Mars** is lost in the Sun's glare this month • **Jupiter** rises before sunset and transits in the late evening • **Saturn** transits in the early evening and sets at midnight.

November Sun & Planets

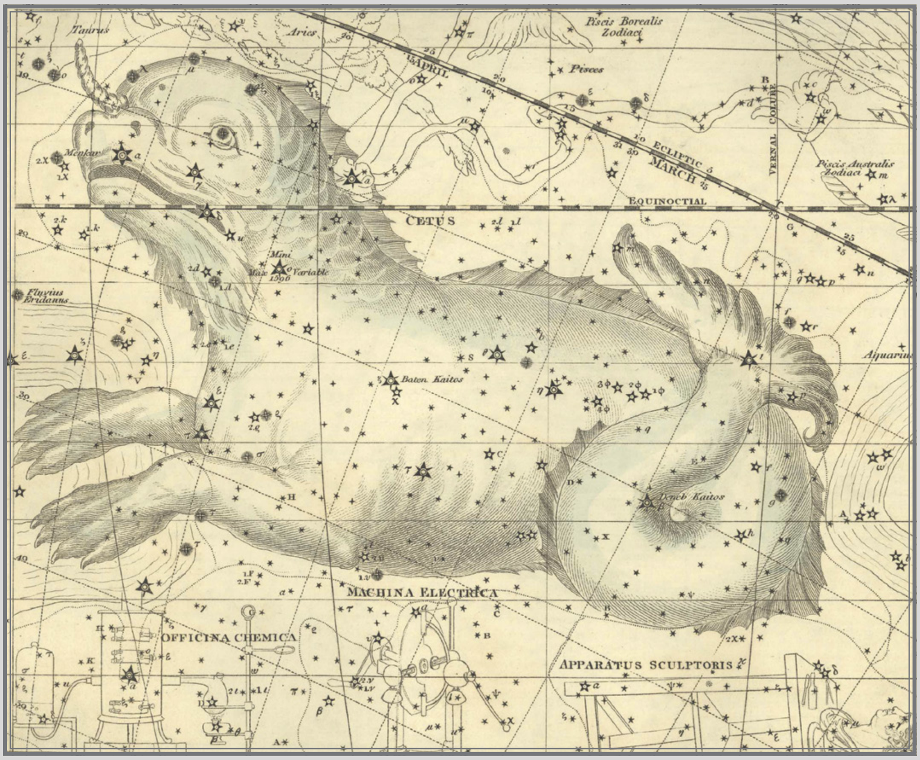
	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$14^h 22.4^m$	–14° 10′	—	–26.8	32′ 13″	—	0.993
	30	$16^h 21.4^m$	–21° 30′	—	–26.8	32′ 26″	—	0.986
Mercury	1	$14^h 51.0^m$	–16° 56′	7° Ev	–0.8	4.7″	98%	1.428
	11	$15^h 53.1^m$	–21° 50′	13° Ev	–0.5	4.9″	94%	1.374
	21	$16^h 56.0^m$	–24° 55′	18° Ev	–0.4	5.3″	87%	1.264
	30	$17^h 49.9^m$	–25° 52′	21° Ev	–0.5	6.0″	74%	1.111
Venus	1	$11^h 30.7^m$	+3° 49′	46° Mo	–4.4	22.1″	55%	0.755
	11	$12^h 11.4^m$	+0° 13′	45° Mo	–4.4	20.1″	59%	0.829
	21	$12^h 53.4^m$	–3° 43′	44° Mo	–4.3	18.5″	64%	0.903
	30	$13^h 32.3^m$	–7° 21′	43° Mo	–4.2	17.2″	67%	0.967
Mars	1	$14^h 43.2^m$	–15° 45′	5° Ev	+1.5	3.7″	100%	2.545
	16	$15^h 25.2^m$	–18° 47′	1° Ev	+1.4	3.7″	100%	2.529
	30	$16^h 06.4^m$	–21° 06′	4° Mo	+1.4	3.7″	100%	2.505
Jupiter	1	$2^h 34.0^m$	+13° 37′	177° Mo	–2.9	49.5″	100%	3.982
	30	$2^h 19.9^m$	+12° 32′	150° Ev	–2.8	48.1″	100%	4.103
Saturn	1	$22^h 11.6^m$	–13° 02′	112° Ev	+0.7	17.8″	100%	9.336
	30	$22^h 13.7^m$	–12° 47′	84° Ev	+0.9	16.9″	100%	9.808
Uranus	16	$3^h 13.1^m$	+17° 36′	178° Ev	+5.6	3.8″	100%	18.632
Neptune	16	$23^h 42.4^m$	–3° 17′	122° Ev	+7.8	2.3″	100%	29.374

The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial diameter.) Last are the percentage of a planet's disk illuminated by the Sun and the distance from Earth in astronomical units. (Based on the mean Earth–Sun distance, 1 a.u. equals 149,597,871 kilometers, or 92,955,807 international miles.) For other timely information about the planets, visit **skyandtelescope.org**.



Seeking Sights in Cetus

Whale or Sea Monster, the enormous constellation is a naked-eye delight.



▲ **WHALE OF A MONSTER** In mythology, Cetus is either a sea monster or, as depicted in this chart from Alexander Jamieson's 1822 *Celestial Atlas*, a rather menacing-looking whale.

ALEXANDER JAMIESON / *CELESTIAL ATLAS* (1822) / UNITED STATES NAVAL OBSERVATORY LIBRARY / PUBLIC DOMAIN

The great Greek myth of Perseus, the Hero, is represented by no fewer than six autumn constellations. Five of them — Perseus, Andromeda, Pegasus, Cassiopeia, and Cepheus — occupy a huge, unbroken swath of the heavens. The sixth is Cetus, the Whale (or Sea Monster), which is separated from the others by Pisces, the Fish.

During long November nights, Cetus seems to swim tail-first across the southern horizon. The tail is marked by what is usually the constellation's brightest star, 2.0-magnitude Beta (β) Ceti, also known as Deneb Kaitos, or Diphda. Deneb Kaitos translates as "the tail of the whale," while Diphda means "frog" and is derived from an early Arabic imagining in which the star is one of two frogs. The other frog is Fomalhaut, a much brighter luminary in Piscis Austrinus, the Southern Fish.

On autumn evenings, you should have little trouble identifying both frogs so long as your view toward the southeast and the south isn't blocked by buildings or trees. Fomalhaut is more than 10° farther south than Diphda, which means it's visible for fewer hours each night. For observers at mid-northern latitudes, there is a period in the early evenings in November during which the two stars are roughly at the same altitude — Fomalhaut is nearly at its highest while Diphda is still rising in the southeast.

Coincidentally, a similar positional relationship exists between Cetus's tail and its head, a flattened pentagon with Alpha (α) Ceti at its easternmost point. A couple of hours after the head rises it's at roughly the same altitude as the tail. In reality, the head is actually farther north than the tail and sticks up just above the celestial equator like a whale rising to the water's surface to spout. As it happens, the right ascension (west to east) difference between Fomalhaut and Diphda is a bit less than 2 hours, while the span from Diphda to the head of Cetus is only slightly more.

Let's look more closely at the head of Cetus. On our center star chart (pages 42 and 43), it's depicted as a rather compact polygon connected to the rest of the constellation by a single line, which gives the impression of a very unwhalelike long, skinny neck. But perhaps that's not an unreasonable depiction if we consider the Perseus myth in which the creature attacking Andromeda, the Chained Maiden, was an unspecified "sea monster" rather than a whale.

The brightest star in the head of Cetus is Alpha Ceti, also called Menkar. Although Menkar is the constellation's Alpha star, at magnitude 2.5 it's actually half a magnitude dimmer than Beta Ceti. Nearly 7° southeast of Alpha is 4.1-magnitude Delta (δ) Ceti. Delta is notable for lying just ⅓° north of the celestial equator. Roughly midway along Cetus's width we arrive at the belly of the beast, 3.7-magnitude Zeta (ζ) Ceti. The star is also known as Baten Kaitos, which translates as "the Sea Monster's Belly."

You might have noticed that earlier in this column I said that Diphda was *usually* the brightest star in Cetus. That cautious wording was in deference to Omicron (ο) Ceti, better known as Mira, the most famous and brightest long-period variable star. It usually ranges in brightness from magnitude 2.0 to 10.1 over a 332-day period. Unfortunately, Mira was last at maximum (when it peaked at magnitude 3) in June this year, and by November it surely will have dimmed to below naked-eye visibility. But it's worth keeping an eye on because sometimes it surprises. In 1779, Mira not only outshined Diphda, it rivaled 1st-magnitude Aldebaran, in Taurus!

■ **FRED SCHAAF** loves observing all celestial creatures great and small.

To find out what's visible in the sky from your location, go to skyandtelescope.org.

A Busy Dawn for Venus

The Morning Star has close encounters with the Moon and Spica.

THURSDAY, NOVEMBER 2

The month opens with a striking configuration featuring the **Moon** and the two brightest stars in Gemini, **Castor** and **Pollux**. The trio clears the east-northeastern horizon at around 10:30 p.m. local daylight-saving time and are neatly arranged as a sideways, isosceles triangle with the waning gibbous Moon positioned at its apex. The Moon's eastward motion reshapes the figure over the course of the night, and by morning the alignment more closely resembles a right triangle. Diehard geometry fans rejoice! You can catch one triangle before going to bed on the 2nd and wake up to a different one on the morning of the 3rd.

THURSDAY, NOVEMBER 9

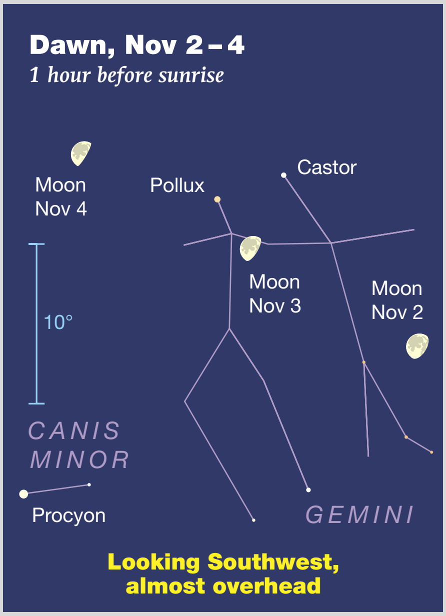
The most spectacular event this month is a tight dawn pairing featuring the waning crescent **Moon** and brilliant **Venus** in Virgo. Conjunctions involving these two are always eye-catching, but this one is extra special. Depending on where in North America you are, perhaps as little as ½° (one Moon diameter) separates them. Observers on the East Coast get the closest conjunction, because by the time the pair rises out west the Moon will have drifted a little farther past Venus. However, if you're fortunate enough to be in Europe or northern Africa, you get to see something even more exciting: a daylight occultation.

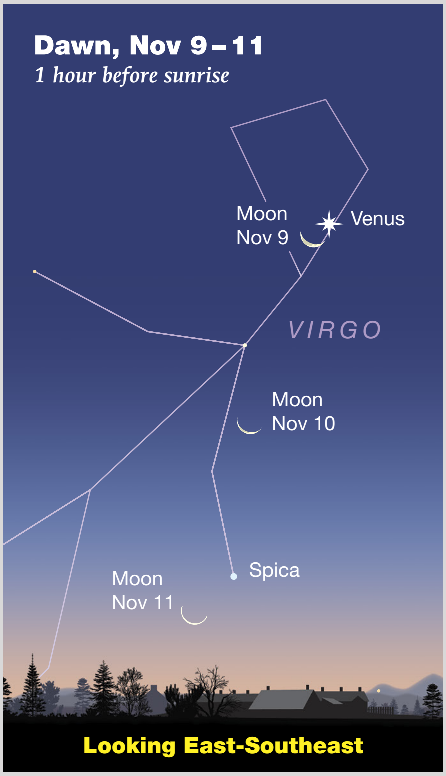
On the morning of their meet-up, Venus gleams at magnitude –4.4, while the Moon is a beautifully earthlit, 15%-illuminated crescent. Together they'll be a wonderful naked-eye sight, but the view in binoculars or a small telescope will be even more impressive.

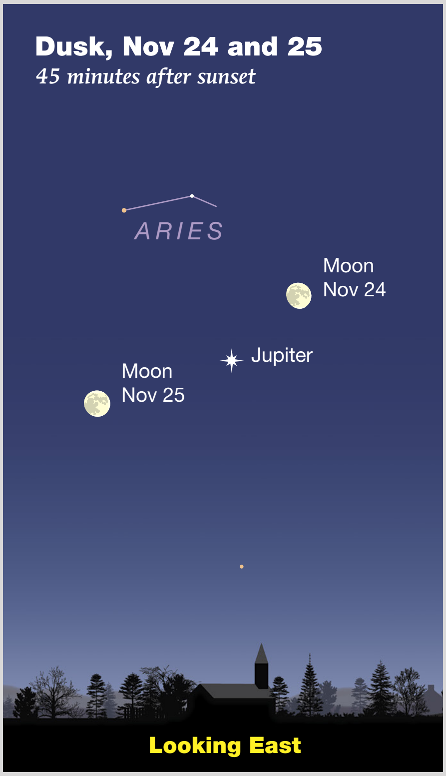
SATURDAY, NOVEMBER 11

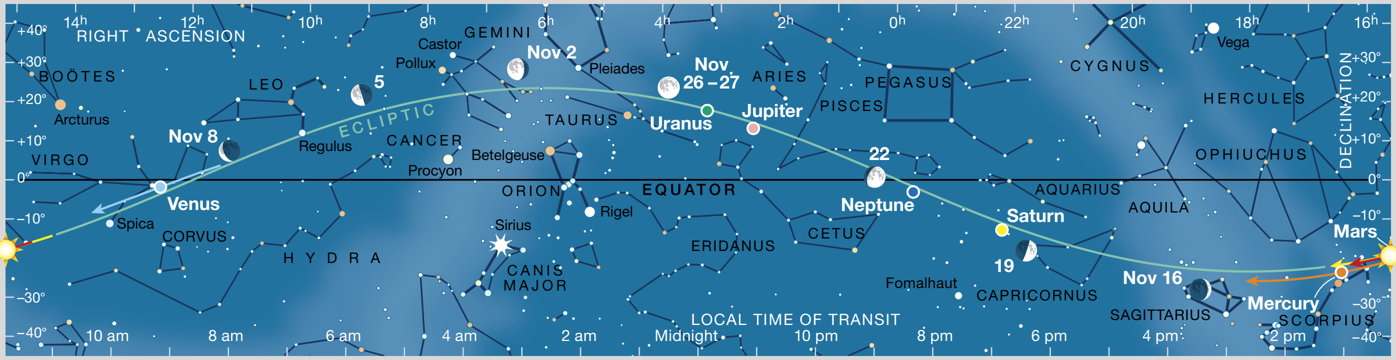
One thing about the constellation Virgo is that it's big. In terms of area, it's the second largest of the 88 officially recognized constellations — only Hydra occupies more celestial real estate. And so,

▼▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your fist at arm's length. For clarity, the Moon is shown three times its actual apparent size.









▲ The Sun and planets are positioned for mid-November; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st and an hour earlier at month's end.

two full days after its encounter with Venus, the **Moon** is still in Virgo when it meets up with the celestial Maiden's leading light, 1st-magnitude **Spica**. As with the Venus conjunction, this one is also for early risers. The duo clears the east-southeastern horizon shortly before 5 a.m. local standard time, with roughly 3° of sky between them.

What makes this event so visually appealing is that the Moon is thumbnail-thin, around 4% illuminated, and only two days from new phase. That means the crescent should display a healthy dose of earthshine, especially if you look soon after moonrise when the sky is darkest. Here again, binoculars will enhance the view considerably.

MONDAY, NOVEMBER 20

The **Moon** was new on the morning of the 13th, and by the 15th it was a reasonably conspicuous waning crescent at dusk. In the evenings that followed, the Moon climbed higher and traversed the zodiacal constellations Sagittarius and Capricornus on its way to Aquarius, where it now pulls up alongside **Saturn**. The two objects don't get especially close this time around, but this evening finds them high in the south with a bit more than 5° separating them. The Moon is some 12 hours past first-quarter phase and positioned left of the +0.8-magnitude ringed planet. Given how faint most of the nearby stars are, the luminous duo easily dominates the region. The only distraction is 1.2-magnitude Fomalhaut, situated more than 16° below the Moon in the faint autumn constellation Piscis Austrinus.

FRIDAY, NOVEMBER 24

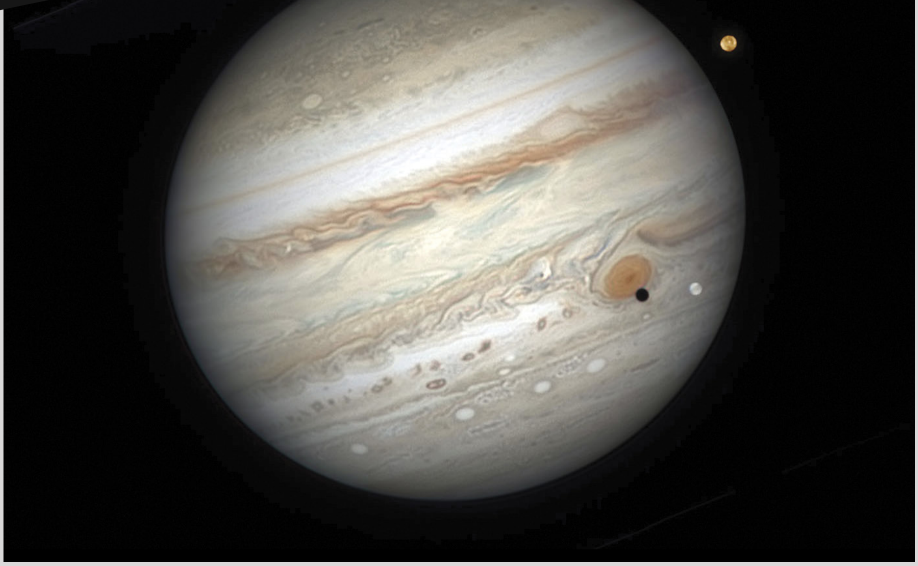
As soon as it begins to get dark, cast your gaze toward the eastern horizon to see the nearly full, waxing gibbous **Moon** rising alongside **Jupiter**. The giant planet is just three weeks past opposition (as noted on page 48) and shines nearly at its brightest, at magnitude –2.8. Only the conjunction between the lunar crescent and Venus on the 9th is more eye-catching this month. In the early evening the Moon lies about 5½° above right of Jupiter, but you'll want to set an early alarm for the next morning. Throughout the night the Moon closes in on Jupiter, and by the time they sink toward the western horizon before dawn on the 25th, the gap between them has closed to just 2°.

WEDNESDAY, NOVEMBER 29

Venus reached greatest elongation from the Sun on October 23rd, and now, a little more than one month later, it still rides high in the dawn sky. Indeed, its current apparition continues until next June, though the planet will be lost to the Sun's glare in early April, after which it will reappear at dusk in July. At present the Morning Star resides in Virgo, where it has spent November slowly drifting toward **Spica**. At last, it's at its closest to the star this morning. The pair rises a little before 3:30 a.m. local standard time, but there's no need to rush out at that early hour — the best view happens in brightening twilight, at around 6 a.m. By then Venus and Spica hang a generous 25° above the southeastern horizon, where they're separated by less than 4½° — close enough to be seen together in binoculars.

It's worth making the effort to take in this morning's event, as observable encounters between Venus and a 1st-magnitude star don't occur very often. The next one isn't until January 7th next year, when the planet sits more than 6° from Antares in Scorpius. After that, it's a long dry spell until September 2024 when Venus once again meets up with Spica, this time low in the twilight evening sky.

■ Consulting Editor **GARY SERONIK** rarely rises voluntarily before dawn. That is, unless Venus is up.



◀ This October 2, 2022, photo by UK imager Damian Peach shows Jupiter in all its glory, including numerous belts and zones, gray-blue festoons, stormy ovals, and the Great Red Spot. Io, at upper right, and Europa and its shadow enhance the scene. The GRS has been shrinking for decades and is currently about 1.3 Earth diameters wide.

A Jupiter and Uranus Double Opposition

Two big planets are at their best this month.

Cold November nights might make you think twice about setting up your scope, but who can resist an invitation from Jupiter? Or Uranus? This month, both planets reach opposition. For Jupiter, that occurs on the night of November 2–3, while Uranus follows suit 10 days later on the 13th.

At opposition, Jupiter is sitting pretty at a declination of +13.5° in Aries, where it shines all night at magnitude –2.9 and presents telescope users with a disk measuring 49.5″ across. But even 10× binoculars will clearly show the gas giant's nonstellar nature and reveal two or three of its four Galilean moons: Io, Europa, Ganymede, and Callisto.

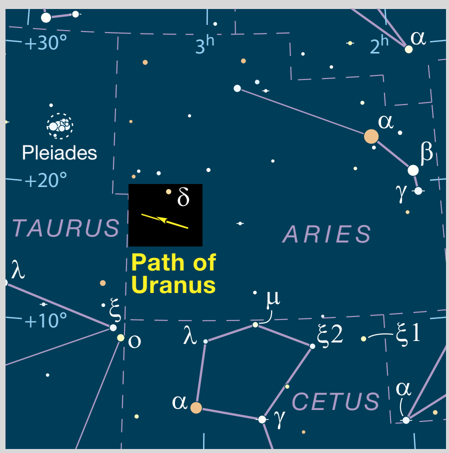
In telescopes with apertures as small as 4 inches (100 mm), Jupiter is a meteorological paradise displaying alternating dark cloud belts and bright zones, and raging storms, including one gigantic (though shrinking) iconic tempest: the Great Red Spot (GRS). Under good conditions, you can also see dusky, blue-grey *festoons* — arc-shaped cloud formations that often sweep south from the North Equatorial Belt into the bright Equatorial Zone. Festoons frequently appear one after another in succession and remind me of earthly *virgas*, dark trails of rain or snow falling from clouds that evaporate before reaching the ground.

Jupiter rotates rapidly, completing one full spin in slightly less than 10 hours. This means features drift all the way across the planet's face in a few hours. If the GRS straddles the central meridian at the start of your observing session, it will butt up against the planet's western limb just two hours later. (Turn to page 50 for a listing of GRS transit times.)

About every six years the orbits of Jupiter and Earth become *coplanar*. At such times, we face Jupiter's equator squarely, and the tilt of its poles is close to zero. This last occurred in 2021 and will do so again in 2026. Because the four bright Galilean moons circle the planet very close to its equatorial plane, we view their orbits edge-on as they (and their shadows) cross the planet's Equatorial Zone.

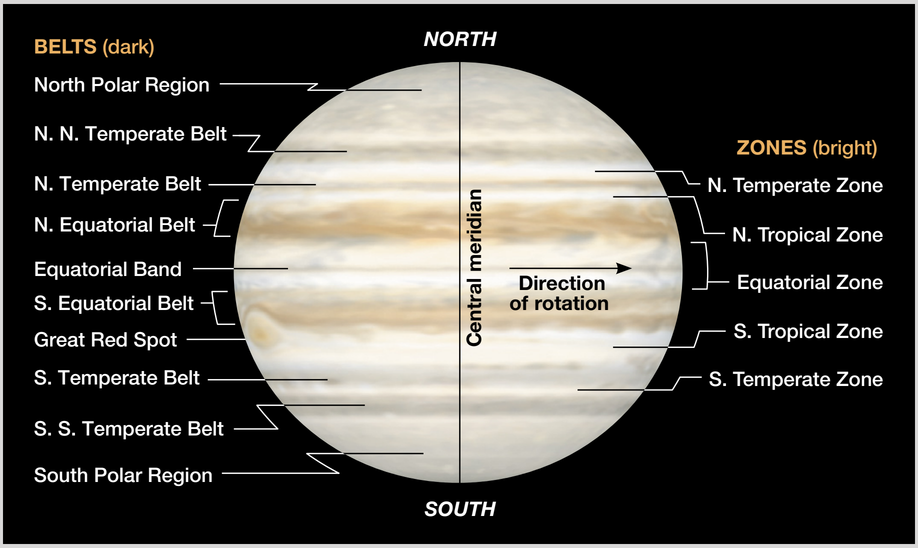
On opposition night this year, Jupiter's north pole tilts 3.4° in Earth's direction. Close-orbiting Io and its shadow still hug the equatorial region during transits, but more distant moons like Ganymede transit and cast shadows well south of the equator. Callisto, the most remote of the quartet, avoids the Jovian disk altogether, passing north and south of the planet during its 16-day orbit. Not a single transit, eclipse, or occultation of Callisto occurs until July 2025 when Earth and Jupiter's orbits once again align.

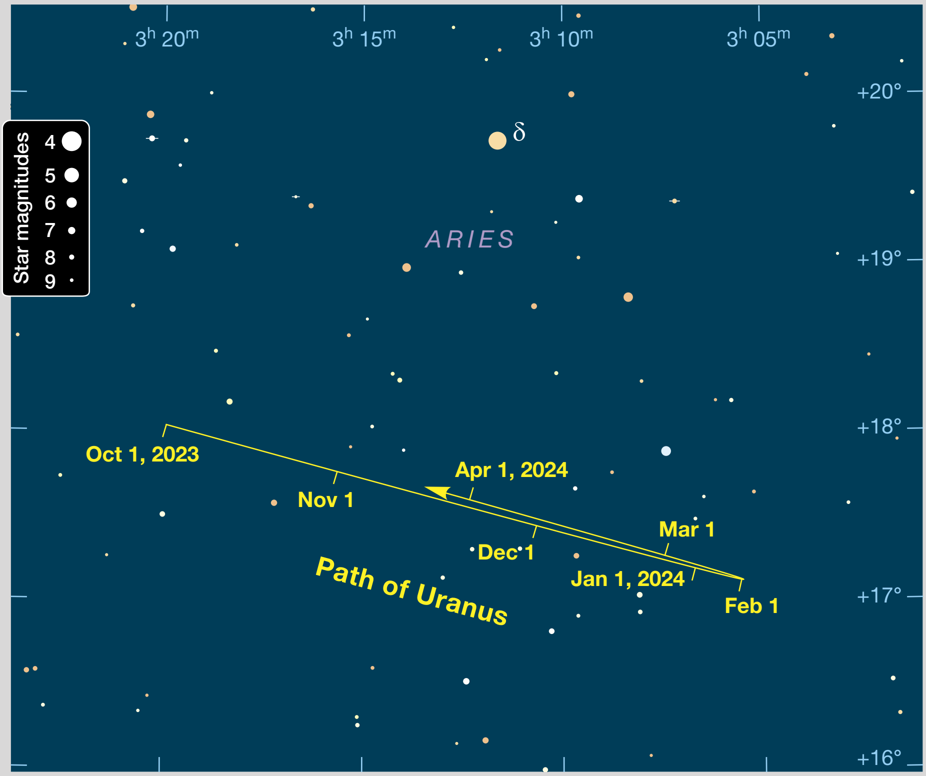
While Jupiter may be a dominant presence this autumn, it shares Aries with another planet: Uranus. As both planets retrograde westward across the constellation during November, their separation increases from 11° on the 1st to a bit more than 13° by month's end. Around its opposition, Uranus will be faintly visible to the naked eye from dark skies, glowing at magnitude 5.6. Zeroing in on its field is straightforward. Your best bet is to look 2° south-southeast of 4.4-magnitude Delta (δ) Arietis.



No stars brighter than magnitude 6.1 trouble the view, which makes a naked-eye sighting of the planet much easier.

A 4-inch or larger telescope magnifying at around 100× will reveal Uranus's 3.8″-wide, blue-green disk. That's only slightly more than twice the apparent size of Jupiter's largest moon, Ganymede. Larger instruments can pull in the two biggest and brightest Uranian satellites, Titania (magnitude 13.8) and Oberon (14.0). An occulting bar mounted on the field stop of a high-magnification eyepiece will make seeing the faint moons easier. Because Uranus presents its south pole toward Earth, its moons describe wide ellipses that reach maximum elongation (roughly 30″ for Titania and 42″ for Oberon) approximately north and south of the planet. To know where and when to look for them, visit the Tools page of **skyandtelescope.org** for our "Moons of Uranus" interactive observing aid.





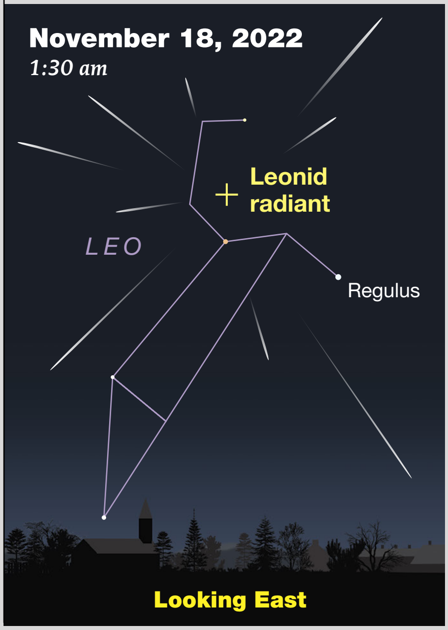
JUPITER BELT DIAGRAM: S&T

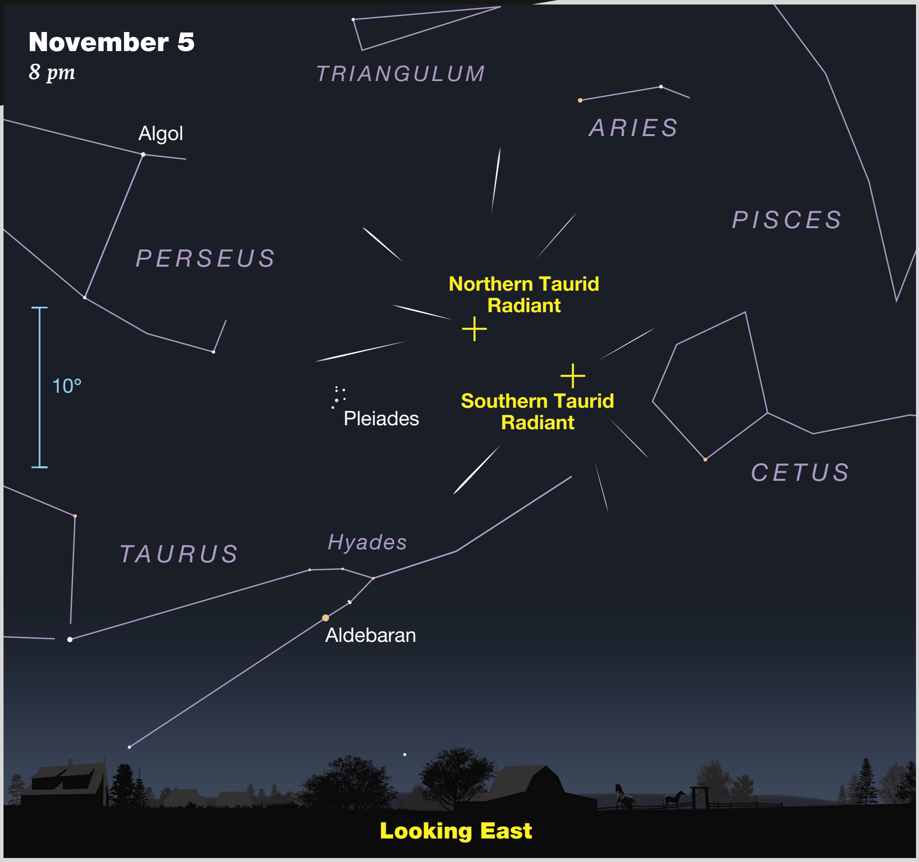
Minor Showers Get a Fair Shake

THIS IS AN IDEAL YEAR for three minor meteor showers that rarely make the hit parade — the Northern and Southern Taurids and the Leonids. While the Leonids are famous for storms that occur approximately every 33 years, off-years receive little attention outside of meteor-observing circles. However, conditions couldn't be better for this trio of minor showers, with little-to-no interference from the Moon around the dates of their predicted maxima.

The Southern and Northern Taurids peak on the nights of November 5–6 and November 12–13, respectively. Both displays have broad maxima, making the entire first half of the month suitable for viewing. The Taurid streams are associated with Comet 2P/Encke and radiate from a 20°-by-10° region south of the Pleiades star cluster in Taurus. Rates are minuscule at a mere 5–10 meteors per hour for the Northern Taurids and 5 per hour for its partner.

The Leonids peak on the night of November 17–18, when you can





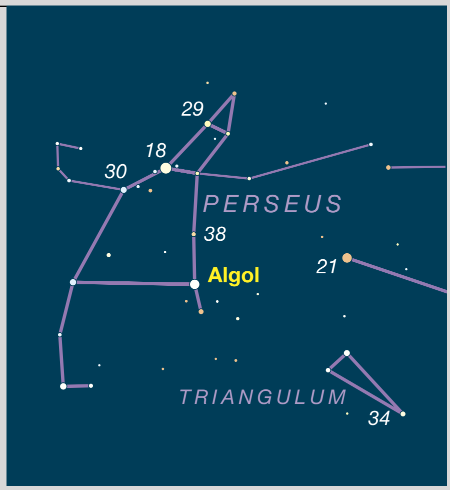
expect to see around 15 meteors per hour from a dark-sky location. The radiant lies in the Sickle asterism in Leo, which is well placed from 2 a.m. until dawn, local time. You can't mistake a Leonid. Not only will its direction of travel point back to the Sickle, but the display produces some of the fastest meteors from a major shower.

If you stowed away that reclining chair at the end of summer, it's time to dig it out again for some meteor watching.

Minima of Algol

Oct.	UT	Nov.	UT
1	13:15	2	2:12
4	10:04	4	23:01
7	6:53	7	19:50
10	3:42	10	16:39
13	0:30	13	13:28
15	21:19	16	10:17
18	18:08	19	7:06
21	14:57	22	3:55
24	11:46	25	0:44
27	8:34	27	21:33
30	5:23	30	18:22

These geocentric predictions are from the recent heliocentric elements Min. = JD 2457360.307 + 2.867351E, where E is any integer. They were derived by Roger W. Sinnott from 15 photoelectric series in the AAVSO database acquired during 2015–2020 by Wolfgang Vollmann, Gerard Samolyk, and Ivan Sergey. For a comparison-star chart and more info, see **skyandtelescope.org/algol**.



▲ Perseus approaches the zenith after midnight in November. Every 2.87 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

Action at Jupiter

JUPITER REACHES OPPOSITION this month on the 3rd. For planetary enthusiasts this marks the beginning of the best part of the telescopic Jupiter-observing season as the planet rises at sunset, transits the meridian around midnight, and is greater than 20° altitude until just before the start of morning astronomical twilight. You could, in effect, productively watch Jupiter from dusk to dawn if you wished, though most will opt to time an observing session to coincide with a Great Red Spot transit or an interesting satellite event. At opposition, the planet's disk swells to a generous 49.5″ as it beams at magnitude –2.9 from southern Aries. (Turn to page 48 for more on observing Jupiter.)

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. The moons orbit Jupiter at different rates, changing positions along an almost straight line from our point of view on Earth. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for when Jupiter is at its highest.

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Standard Time is UT minus 5 hours.)

October 1: 2:15, 12:11, 22:07: **2**: 8:02, 17:58: **3**: 3:53, 13:49, 23:44: **4**: 9:40, 19:36: **5**: 5:31, 15:27: **6**: 1:22, 11:18, 21:14: **7**: 7:09, 17:05: **8**: 3:00, 12:56, 22:51: **9**: 8:47, 18:43: **10**: 4:38, 14:34: **11**: 0:29, 10:25, 20:21: **12**: 6:16, 16:12: **13**: 2:07, 12:03, 21:58: **14**: 7:54, 17:50: **15**: 3:45, 13:41, 23:36: **16**: 9:32, 19:27: **17**: 5:23, 15:19: **18**: 1:14, 11:10, 21:05: **19**: 7:01, 16:57: **20**: 2:52, 12:48, 22:43: **21**: 8:39, 18:34: **22**: 4:30, 14:26: **23**: 0:21, 10:17, 20:12: **24**: 6:08, 16:03: **25**: 1:59, 11:55, 21:50: **26**: 7:46, 17:41: **27**: 3:37, 13:33, 23:28: **28**: 9:24, 19:19:

29: 5:15, 15:10: **30**: 1:06, 11:02, 20:57: **31**: 6:53, 16:48

November 1: 2:44, 12:40, 22:35; **2**: 8:31, 18:26; **3**: 4:22, 14:17; **4**: 0:13, 10:09, 20:04; **5**: 6:00, 15:55; **6**: 1:51, 11:47, 21:42; **7**: 7:38, 17:33; **8**: 3:29, 13:25, 23:20; **9**: 9:16, 19:11; **10**: 5:07, 15:02; **11**: 0:58, 10:54, 20:49; **12**: 6:45, 16:40; **13**: 2:36, 12:32, 22:27; **14**: 8:23, 18:18; **15**: 4:14, 14:10; **16**: 0:05, 10:01, 19:56; **17**: 5:52, 15:48; **18**: 1:43, 11:39, 21:35; **19**: 7:30, 17:26; **20**: 3:21, 13:17, 23:13; **21**: 9:08, 19:04; **22**: 4:59, 14:55; **23**: 0:51, 10:46, 20:42; **24**: 6:38, 16:33; **25**: 2:29, 12:24, 22:20; **26**: 8:16, 18:11; **27**: 4:07, 14:03, 23:58; **28**: 9:54, 19:49; **29**: 5:45, 15:41; **30**: 1:36, 11:32, 21:28

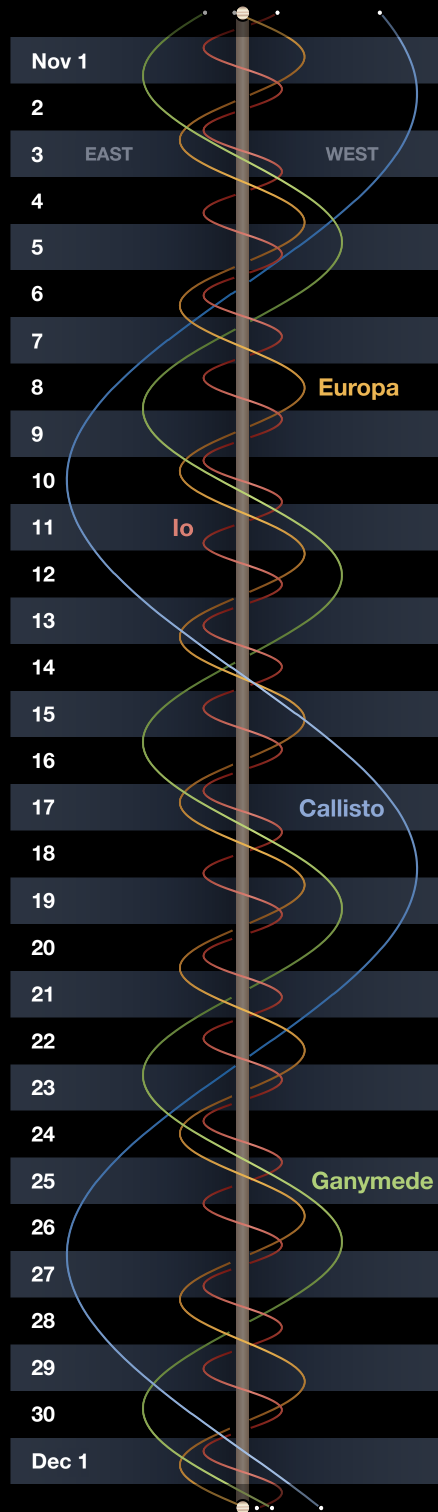
These times assume that the spot will be centered at System II longitude 46° on November 1st. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 46° and 1⅔ minutes later for each degree more than 46°.

Phenomena of Jupiter's Moons, November 2023

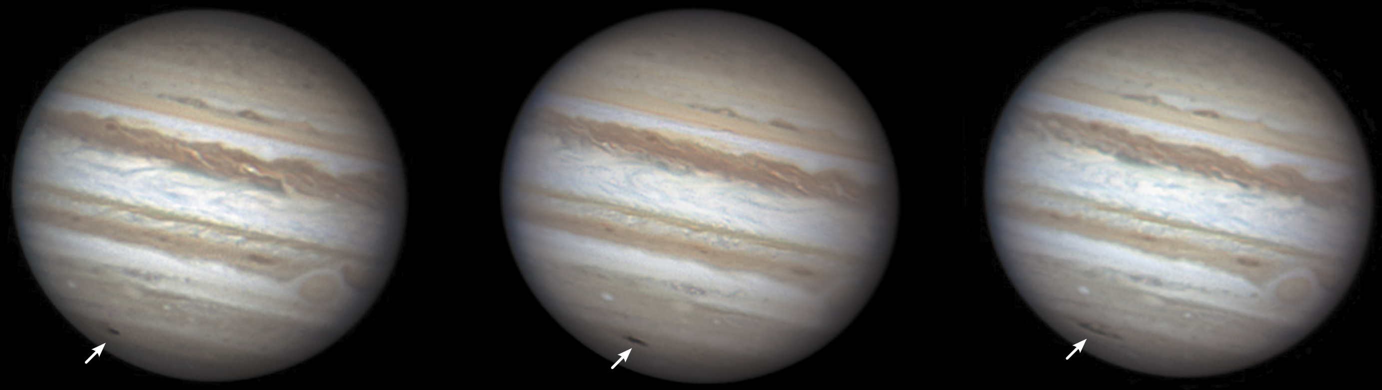
Nov. 1	14:59	I.Sh.I
	15:03	I.Tr.I
	17:10	I.Sh.E
	17:11	I.Tr.E
Nov. 2	6:12	II.Ec.D
	8:33	II.Ec.R
	12:19	I.Ec.D
	14:29	I.Oc.R
Nov. 3	9:28	I.Sh.I
	9:29	I.Tr.I
	11:37	I.Tr.E
	11:38	I.Sh.E
	13:59	III.Sh.I
	14:18	III.Tr.I
	15:18	III.Tr.E
	15:42	III.Sh.E
Nov. 4	1:15	II.Sh.I
	1:15	II.Tr.I
	3:28	II.Tr.E
	3:34	II.Sh.E
	6:47	I.Oc.D
	8:58	I.Ec.R
Nov. 5	3:54	I.Tr.I
	3:57	I.Sh.I
	6:03	I.Tr.E
	6:07	I.Sh.E
	19:26	II.Oc.D
	21:52	II.Ec.R
Nov. 6	1:12	I.Oc.D
	3:26	I.Ec.R
	22:20	I.Tr.I
	22:26	I.Sh.I
Nov. 7	0:29	I.Tr.E
	0:36	I.Sh.E
	3:44	III.Oc.D
	5:36	III.Ec.R
	14:22	II.Tr.I
	14:33	II.Sh.I
	16:35	II.Tr.E
	16:52	II.Sh.E
	19:38	I.Oc.D
	21:55	I.Ec.R
Nov. 8	16:46	I.Tr.I
	16:54	I.Sh.I
	18:55	I.Tr.E
	19:05	I.Sh.E
Nov. 9	8:33	II.Oc.D
	11:11	II.Ec.R
	14:04	I.Oc.D
	16:24	I.Ec.R
Nov. 10	11:12	I.Tr.I
	11:23	I.Sh.I
	13:21	I.Tr.E
	13:34	I.Sh.E
	17:31	III.Tr.I
	18:02	III.Sh.I
	18:37	III.Tr.E
	19:44	III.Sh.E
Nov. 11	3:28	II.Tr.I
	3:51	II.Sh.I
	5:42	II.Tr.E
	6:10	II.Sh.E
	8:30	I.Oc.D
	10:52	I.Ec.R
Nov. 12	5:38	I.Tr.I
	5:52	I.Sh.I
	7:47	I.Tr.E
	8:02	I.Sh.E
	21:41	II.Oc.D
Nov. 13	0:30	II.Ec.R
	2:56	I.Oc.D
	5:21	I.Ec.R
Nov. 14	0:04	I.Tr.I
	0:21	I.Sh.I
	2:13	I.Tr.E
	2:31	I.Sh.E
	6:56	III.Oc.D
	9:36	III.Ec.R
	16:35	II.Tr.I
	17:08	II.Sh.I
	18:49	II.Tr.E
	19:28	II.Sh.E
	21:22	I.Oc.D
	23:50	I.Ec.R
Nov. 15	18:30	I.Tr.I
	18:50	I.Sh.I
	20:39	I.Tr.E
	21:00	I.Sh.E
Nov. 16	10:48	II.Oc.D
	13:49	II.Ec.R
	15:48	I.Oc.D
	18:18	I.Ec.R
Nov. 17	12:56	I.Tr.I
	13:18	I.Sh.I
	15:05	I.Tr.E
	15:29	I.Sh.E
	20:44	III.Tr.I
	21:57	III.Tr.E
	22:04	III.Sh.I
	23:45	III.Sh.E
Nov. 18	5:42	II.Tr.I
	6:26	II.Sh.I
	7:56	II.Tr.E
	8:46	II.Sh.E
	10:14	I.Oc.D
	12:47	I.Ec.R
Nov. 19	7:22	I.Tr.I
	7:47	I.Sh.I
	9:31	I.Tr.E
	9:58	I.Sh.E
	23:56	II.Oc.D
Nov. 20	3:08	II.Ec.R
	4:40	I.Oc.D
	7:16	I.Ec.R
Nov. 21	1:49	I.Tr.I
	2:16	I.Sh.I
	3:58	I.Tr.E
	4:26	I.Sh.E
	10:10	III.Oc.D
	11:30	III.Oc.R
	11:54	III.Ec.D
	13:37	III.Ec.R
	18:49	II.Tr.I
	19:44	II.Sh.I
	21:03	II.Tr.E
	22:03	II.Sh.E
	23:06	I.Oc.D
Nov. 22	1:45	I.Ec.R
	20:15	I.Tr.I
	20:45	I.Sh.I
	22:24	I.Tr.E
	22:55	I.Sh.E
Nov. 23	13:04	II.Oc.D
	16:27	II.Ec.R
	17:32	I.Oc.D
	20:13	I.Ec.R
Nov. 24	14:41	I.Tr.I
	15:14	I.Sh.I
	16:50	I.Tr.E
	17:24	I.Sh.E
Nov. 25	0:00	III.Tr.I
	1:20	III.Tr.E
	2:06	III.Sh.I
	3:47	III.Sh.E
	7:57	II.Tr.I
	9:02	II.Sh.I
	10:11	II.Tr.E
	11:21	II.Sh.E
	11:58	I.Oc.D
	14:42	I.Ec.R
Nov. 26	9:07	I.Tr.I
	9:43	I.Sh.I
	11:17	I.Tr.E
	11:53	I.Sh.E
Nov. 27	2:13	II.Oc.D
	5:47	II.Ec.R
	6:24	I.Oc.D
	9:11	I.Ec.R
Nov. 28	3:34	I.Tr.I
	4:12	I.Sh.I
	5:43	I.Tr.E
	6:22	I.Sh.E
	13:27	III.Oc.D
	14:53	III.Oc.R
	15:55	III.Ec.D
	17:38	III.Ec.R
	21:04	II.Tr.I
	22:20	II.Sh.I
	23:20	II.Tr.E
Nov. 29	0:39	II.Sh.E
	0:51	I.Oc.D
	3:39	I.Ec.R
	22:00	I.Tr.I
	22:41	I.Sh.I
Nov. 30	0:10	I.Tr.E
	0:51	I.Sh.E
	15:21	II.Oc.D
	19:06	II.Ec.R
	19:17	I.Oc.D
	22:08	I.Ec.R

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons



The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites' positions east or west of Jupiter.



"Powder Burns" on Jupiter

Are we overdue for the appearance of visible impact scars?

Jupiter is a big target. With a diameter over 11 times greater than Earth's and two-and-a-half times the mass of all the other planets combined, it's a veritable cosmic vacuum cleaner, with the highest frequency of impacts of any body in the solar system other than the Sun. Without Jupiter's protecting influence, the inner solar system that we inhabit would be a far more dangerous place.

For eight days in July of 1994, a stream of fragments from Comet Shoemaker-Levy 9 smashed into Jupiter, producing huge clouds of sooty particulates that encircled the planet and lingered for months. These features were not merely dark but jet black, like the shadows cast by Galilean satellites. At the time, it was believed that no one had ever observed a planetary impact before, so their appearance caught astronomers by surprise.

In July 2009 — almost 15 years to the day after the Shoemaker-Levy 9 events — Australian amateur Anthony Wesley captured images of a fresh impact "powder burn" when it rotated into view over Jupiter's morning limb. The impact itself was unobserved because it had occurred only hours earlier on Jupiter's night hemisphere. At first Wesley mistook the feature for a satellite shadow but quickly realized it wasn't.

Observers of the Shoemaker-Levy 9 and Wesley impact scars were struck by a unique hallmark characteristic of these features. Normally, markings in Jupiter's cloud canopy exhibit the highest contrast when they are located near the center of the planet's disc. As they rotate toward the limb, the increased thickness of overlying hazes in our line of sight markedly reduces their contrast, so they tend to disappear just before they rotate around the limb. This did not occur with the Shoemaker-Levy 9 and Wesley spots. They were located high above the haze layers, so as they neared the limb the contrast of these sooty remnants wasn't diminished. Satellite shadows behave this way, too.

During the 14 years since Wesley's discovery, amateurs armed with video cameras have recorded the flashes of 9 bright bolides against the backdrop of Jupiter's sunlit clouds, but none of these events left a detectable blemish on

▲ Anthony Wesley's discovery image on July 19, 2009 (left) captured a compact, black spot that he initially mistook for a satellite shadow. Subsequent images taken on July 24th (center) and August 3rd (right) record the effects of zonal winds shearing the impact scar into an elongated dark streak.

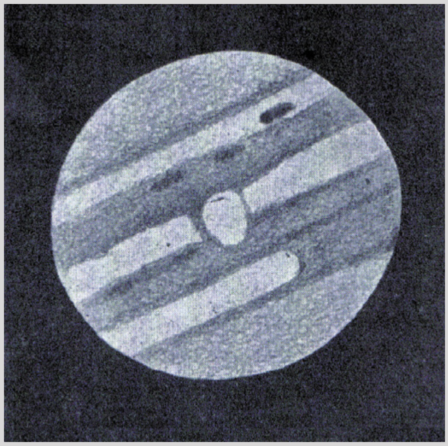
the planet's face. According to Spanish astronomer Agustín Sánchez-Lavega, an expert on planetary atmospheres, impactors larger than 300 meters (1,000 feet) in diameter are required to produce dark debris fields visible through large amateur telescopes that persist for weeks. He estimates that these features ought to be seen once every 7 years or so (*S&T:* Jan. 2022, p. 52). No doubt many are missed because there's only an 8-month window each year when Jupiter is well placed for observation, and the majority of these observations cluster around the date of opposition. In addition, the visibility of impacts at high latitudes on Jupiter's oblate globe is poor.

An exhaustive review of three centuries of Jupiter observations conducted by University of Northern Iowa astronomer Thomas Hockey turned up

half a dozen descriptions of extremely dark spots suggestive of impact scars. However, Hockey concluded that many of these features were merely "barges" — dark reddish-brown cyclonic vortices in Jupiter's atmosphere that often have sharply defined elliptical outlines and usually appear within or along the northern edge of the planet's North Equatorial Belt.

Cosmic collisions were the furthest thing from my mind back in 1999 when I was perusing a copy of *The Nature of the Planets* by Russian astronomer Vsevolod Sharonov, originally published as *Priroda Planet* in 1958. The 1964 English edition features an extensive bibliography loaded with references unfamiliar to most Western readers. One of these titles immediately caught my eye: Zlatinsky, V. M., "*Chernoe pyatno na Yupitere*" ["Black Spot on Jupiter"], *Izvestia Obshchestva Mirovedeniya*. Vladimir Zlatinsky of the University of Kazan's Engelhart Observatory described a very strange dark marking on Jupiter that he observed in August 1917.

The planet wouldn't reach opposition until late November that year, so in mid-August it was a prominent object in the predawn sky. On August 18th, Zlatinsky trained a 4.3-inch refractor on Jupiter. Using a magnification of 185×, he was struck by a "sharp, elliptical and very dark spot in the North Tropical



◀ Vladimir Zlatinsky's sketch depicting his extraordinary "black spot" on August 18, 1917

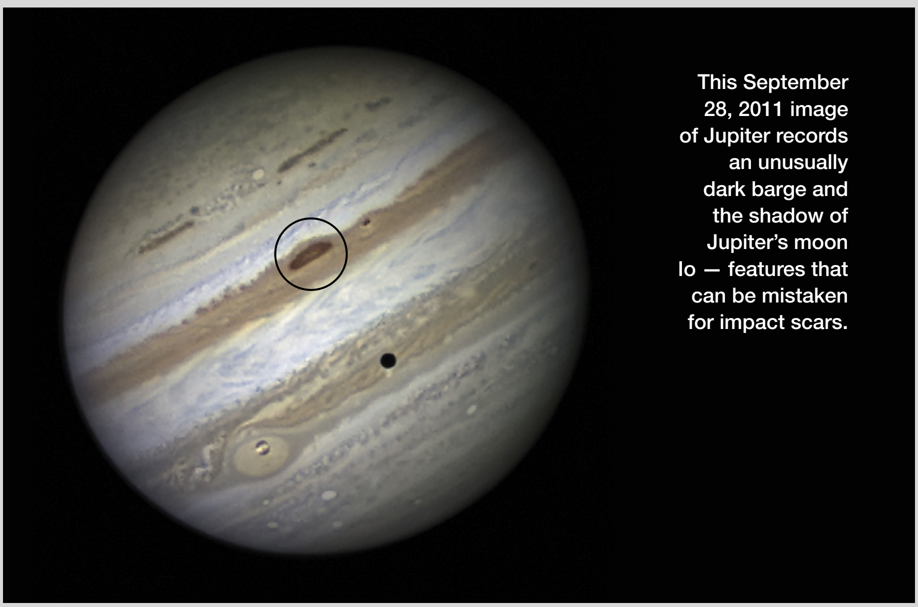
Zone . . . The round trailing edge of the back of the spot I at first assumed to be the shadow of one of Jupiter's moons, but I was perplexed by the unusual appearance of this 'shadow.'"

On the following day Zlatinsky consulted an ephemeris and realized that no shadow transit had occurred the previous night. Later that day he received the latest issue of the German journal *Astronomische Nachrichten* (*Astronomical News*), containing a report by Philipp Fauth, Germany's leading Jupiter observer, announcing his discovery in early July of an exceptionally dark, "violin-shaped" spot in the North Tropical Zone spanning more than 13° of longitude. I'm utterly amazed that the publication managed to reach Zlatinsky during the third year of World War I shortly after the outbreak of revolution in Russia.

Eight nights later Zlatinsky observed the feature for the second time and found the spot ". . . so prominent at the present time that it is the darkest feature on the planet and should be called the 'black spot' to differentiate it from the Great Red Spot, with which it has much in common: both are located in the tropical zone on either side of the equator and are of about the same width."

I'm struck by the fact that when Zlatinsky first glimpsed his "black spot" he mistook part of it for a satellite shadow. His sketch clearly records two barges along the northern edge of the nearby North Equatorial Belt, but he depicts the darkness of these features as far more muted than the black spot. If the length of the black spot on August 26th was comparable to that of the Great Red Spot, which spanned a whopping 33° of longitude in 1917, it would have more than doubled in length since Fauth measured it in early July. This evolution calls to mind the shearing of the Shoemaker-Levy 9 and Wesley impact scars into long, irregular streaks by prevailing east-west winds. Was the 1917 feature really an impact scar that was all but overlooked during one of modern history's most tumultuous years? While the descriptions are very suggestive, there's no mention of undiminished contrast near the planet's limb that would constitute "smoking-gun" evidence of it being an impact scar.

If Sánchez-Lavega's 7-year-frequency estimate is correct, we're long overdue for the appearance of a visible impact scar. That thought makes me want to observe Jupiter every chance I get! The planet reaches opposition on the 3rd this month.



This September 28, 2011 image of Jupiter records an unusually dark barge and the shadow of Jupiter's moon Io — features that can be mistaken for impact scars.

1917 DRAWING: V. M. ZLATINSKY / *IZVESTIA OBSHCHESTVA MIROVEDENIYA* (1917); JUPITER WITH DARK BARGE: DAMIAN PEACH

■ Contributing Editor **TOM DOBBINS** is hoping that the smoke from Canadian wildfires clears before Jupiter's opposition this month.

RON BRECHER

Double Cluster Country

The famous side-by-side cluster pair in Perseus is a gateway to nearby starry targets.

In northernmost Perseus you'll find a two-for-one treasure: **NGC 884** and **NGC 869**, together known as the Double Cluster. They're a glittering deep-sky duo spanning nearly 1° of prime celestial real estate. Gleaming at magnitudes 6.1 and 5.3, respectively, these notable NGCs are even visible to the unaided eye.

Look for the Double Cluster by using neighboring Cassiopeia's helpful W pattern. Simply extend a line from Gamma (γ) Cassiopeiae east-southeastward through Delta (δ) by roughly twice the separation between the stars, and you'll land a tad north of the clusters. The W-to-DC star-hop never fails.

Spotting the DC naked-eye is easy in a dark rural sky, but I can't glimpse it at all through my suburban soup. Even 10×50 binoculars only cough up two gritty lumps with very few stars. Thankfully, telescopes do way better, even from town. Let's take a look.

Double Cluster Details

I examined the Double Cluster and its surroundings last autumn with a 4.7-inch (120-mm) f/7.5 apochromatic refractor and an 8-inch f/6 Newtonian reflector. To start off, I employed a wide-angle 30-mm eyepiece that yields 30× in the refractor and 41× with the reflector. The low-power view in each scope was fab: two star-packed clusters lined up east-west in the star-rich Perseus Milky Way. Of course, the twin clusters aren't *identical* twins — a fact that became more obvious with increasing magnification.

▲ **TWO-FOR-ONE DEAL** NGC 884 (left) and NGC 869 (right) form the stunning Double Cluster in Perseus. NGC 884 is approximately 8,200 light-years from Earth, while NGC 869 is about 100 light-years more distant. Together they contain some 600 blue-white suns only 14 million years old. In contrast, the five bright, reddish-orange pinpoints accompanying NGC 884 are all supergiant variable stars of spectral class *M* — astronomers don't know for certain if the fiery five physically belong to the cluster.

The few hundred blue-white suns of the eastern cluster, NGC 884, are all magnitude 8.0 and dimmer, except for a 6.5-magnitude spark north of the core. In the core itself, I noticed two triangular clumps in total spanning 2.3′ that emerged clearly at about 100× in both scopes. Curiously, the area outside

the central region included five reddish-orange stars. I saw one southeast of center, a pair farther eastward, plus two ruddy sparks to the west and southwest in the gap between the clusters.

The western cluster, NGC 869, is more densely packed and brighter than its sibling. NGC 869 boasts two 6.6-magnitude leaders — one northeast of the core and the other near the center. The latter marks the beaming face of the Parachute Man, a 3′-long pattern that years ago caught the eye of my late observing friend Lance Olkovick. The parachute is formed by a tight curve of five stars, while other stars suggest a torso and legs. Lance's Parachute Man resolved in the refractor at 100× and in the reflector at 75×. Give the little guy a try!

Taking Stock

There's more to see in Double Cluster country. To begin with, it's impossible to miss **ΟΣΣ 25** just west of NGC 869. ΟΣΣ 25 comprises 6.5- and 7.4-magnitude stars a spacious 102.8″ apart, slanted north-northeastward.

Using the refractor at 50×, I followed the aim of ΟΣΣ 25 past NGC 869 to yellowish, 6th-magnitude 7 Persei, then northward to similar 8 Persei, and onward to a chain of stars arcing north-westward. I hopped along the gentle curve to a no-name double (I call it the Pebbles) of 9.7- and 10.1-magnitude stars separated by 38″. Slightly less than ½° farther, I spied a recognized binary, **Σ230**, comprising 7.9- and 9.4-magnitude stars 23.8″ apart. From Σ230, I continued to a 6.4-magnitude star that terminates the chain.

Powering back down to 30×, I turned northward across the Perseus-Cassiopeia border to 7.6-magnitude HD 13437 (it comes with a wide, 9.4-magnitude partner). HD 13437 sits on the south-western edge of a sprawling cluster named **Stock 2**. The refractor framed a starry scatter 1° in diameter; the reflector at 41× produced about 100 stars down to approximately magnitude 11. To my eye, the chain-and-cluster combo invoked a blossoming flower opened to the northeast. Buzzing the flower from that direction was a bee symbolized by the double **ΟΣΣ 26**, whose 7.0- and 7.3-magnitude stars, 62.9″ apart, point toward the cluster.

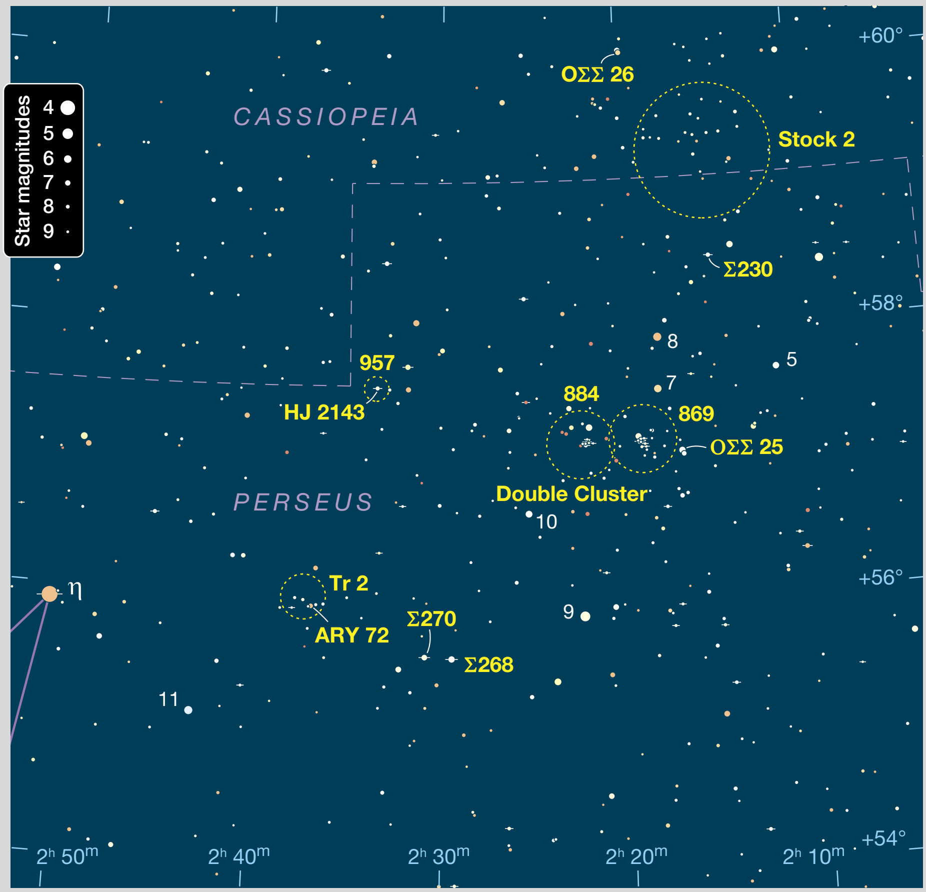
Soaking up the scenery, I realized that ΟΣΣ 26 exhibits essentially the same slant as ΟΣΣ 25, the spacious set west of the Double Cluster. Ditto for the twin leaders inside NGC 869. All three pairs are of similar brightness. Nice!

Eastward and Southward

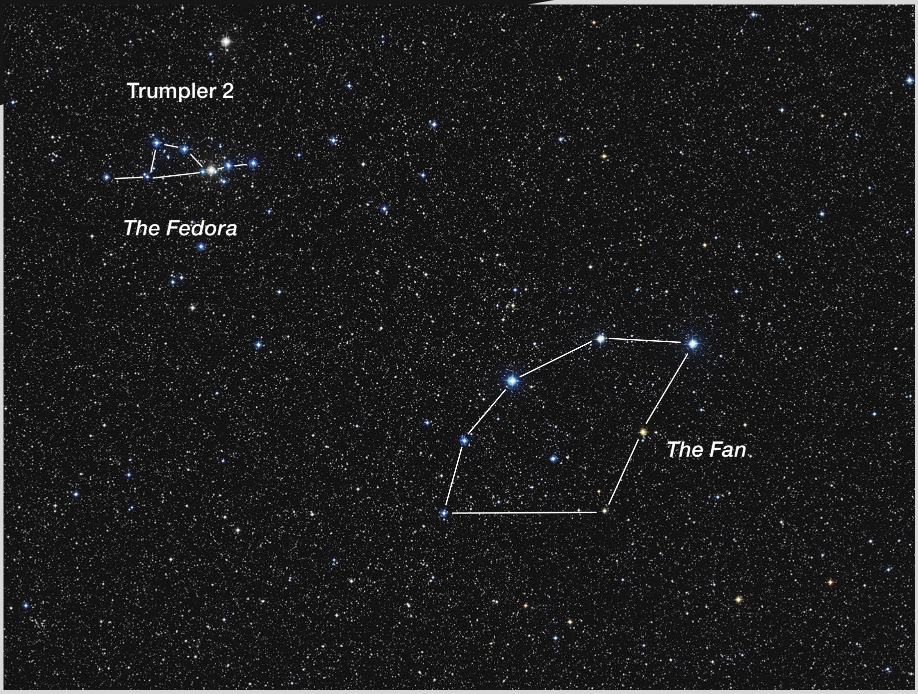
From the Double Cluster, I shifted my gaze 1½° east-northeastward to a Cassiopeia-like W asterism of five stars ranging in magnitude from 6.6 to 8.1. The faintest is **HJ 2143**, which turns out to be a double whose 9.6-magnitude secondary lies 23.5″ northward of the primary. HJ 2143 is also the end point of several 8th- and 9th-magnitude stars that arc into my next target — a small, barely perceptible open cluster.

That pale specimen is **NGC 957**. Its 100-plus stars are all fainter than 11.0-magnitude. However, photos show a prominent portion concentrated north of HJ 2143. My refractor working at 60× unveiled a ghostly mist elongated east-west hugging HJ 2143; upping to 100× partially resolved the mist into several extremely faint stars. The reflector at 41× registered a grainy cloud perhaps 10′ across, and the grain sharpened with magnification. At 135×, I beheld a delicate sprinkle of stardust — hardly dazzling, but not bad.

A 1⅔° drop south-southeastward located **Trumpler 2**, another group of 100-plus stars. Yeah, right! In my backyard optics, Tr 2 was sparse, ragged, and slender. I dubbed it the Fedora. The hat's rim traces along nine 8th- to 10th-magnitude stars in a slightly curvy, east-west line 19′ long. On the rim I saw a 7.7-magnitude orange star anchoring a triple system named



▲ **CLUSTER COUNTRY** Perseus climbs high overhead every autumn. Plotted here in northern Perseus are several star clusters — including the famous Double Cluster — within a few degrees of each other. The glittering Double Cluster was the author's starting point; note how the pair form a right-angle triangle with the much fainter clusters NGC 957 and Trumpler 2.



◀ **FEDORA AND FAN** The slender form of the open cluster Trumpler 2, which the author has dubbed the Fedora, is distinctive in suburban telescopes. Less than 1° southwest of the Fedora is a broad asterism he calls the Fan.

ARY 72. The refractor picked up a 9.3-magnitude companion 69.2″ east (the C component) and another 35.3″ southwest (B) of magnitude 10.0. The 8-inch reflector added a tighter and dimmer duo 2′ farther southwest. Its 9.8- and 11.2-magnitude stars, 25″ apart, were a cinch at 41×. I noted a very similar pair on the rim of the hat to the east. Official binaries? No, but they added flair to my Fedora.

Faint Fanfare

A 40′-wide asterism I call the Fan sits 1° west-southwest of Trumpler 2. The handheld fan is suggested by five roughly equally spaced stars curving southeastward from brightest (magnitude 6.5) to faintest (magnitude 9.0). The fan's straight western side is augmented by 7.9-magnitude HD 15345, a yellow-orange star sporting two 10.7-magnitude attendants. Together they form a triangle 107″ across. The bottom of the fan is marked by a single 8.8-magnitude star.

Every star in the Fan's arc-of-five has a mate. The westernmost point, **Σ268**, features a 6.7-magnitude primary and a 8.5-magnitude secondary 2.9″ to the southeast. The pair was a close split in the refractor at 129×. Only 12′ east, **Σ270** consists of 7.0- and 9.7-magnitude stars 21.3″ apart — easy at 30×. Turning to my larger scope for the other three (strictly unofficial) doubles, I nabbed the 6.8-magnitude #3 star with its 10.5-magnitude outlier 2.6′ west-southwest, and the 8.6-magnitude #4 star holding an 11.3-magnitude flanker 82″ northwest. The 9.0-magnitude #5 star was obvious, but my successful detection of its 12.0-magnitude neighbor 41″ south really surprised me. And something even more surprising caught my eye 10′ farther south.

The 8-inch had captured three anonymous pairings arranged in a squat triangle 11′ wide, oriented east-west. The magnitudes of the six stars range from 10.6 to 11.3, and the three pairs display separations of 18″, 22″, and 33″. The reflector at 41× resolved them just well enough to catch my attention. Increasing to 75× resulted in three distinct doubles in one field of view. In my refractor, they were fuzzy spots at 30× but clean tandems at 100×. It was a satisfying sight.

A suburban sky can be soupy (mine sure is), yet despite the light there are lots of accessible attractions in Double Cluster country. So, folks, double down and get scoping!

■ Contributing Editor **KEN HEWITT-WHITE** enjoys deep-sky rambles even amid city lights.

Double Cluster Plus

Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 884	Open cluster	6.1	18.0′	2^h 22.1^m	+57° 08′
NGC 869	Open cluster	5.3	18.0′	2^h 19.1^m	+57° 09′
ΟΣΣ 25	Double star	6.5, 7.4	102.8″	2^h 16.9^m	+57° 03′
Σ230	Double star	7.9, 9.4	23.8″	2^h 14.9^m	+58° 29′
Stock 2	Open cluster	4.4	60′	2^h 15.6^m	+59° 32′
ΟΣΣ 26	Double star	7.0, 7.3	62.9″	2^h 19.7^m	+60° 02′
HJ 2143	Double star	8.1, 9.6	23.5″	2^h 33.5^m	+57° 32′
NGC 957	Open cluster	7.6	10.0′	2^h 33.4^m	+57° 34′
Tr 2	Open cluster	5.9	20.0′	2^h 37.3^m	+55° 59′
ARY 72 AB	Double star	7.7, 10.0	35.3″	2^h 36.9^m	+55° 55′
ARY 72 AC	Double star	7.7, 9.3	69.2″	2^h 36.9^m	+55° 55′
Σ268	Double star	6.7, 8.5	2.9″	2^h 29.4^m	+55° 32′
Σ270	Double star	7.0, 9.7	21.3″	2^h 30.8^m	+55° 33′

Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

DSS2 ALL SKY SURVEY

Hunt Asteroids at Your Desk

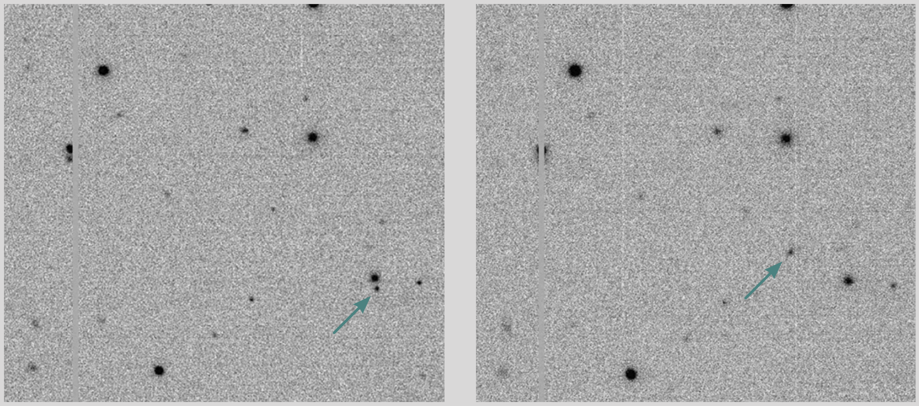
You don't need your own equipment to find asteroids.

Fancy discovering an asteroid but don't have a telescope with which to do so? You're in luck. The International Asteroid Search Collaboration (IASC) — fondly known as Isaac — is aimed at people who want to hunt asteroids and other things that move in the near-Earth sky but who don't have the requisite equipment for such an endeavor.

It's been nearly two decades since citizen-science projects such as Stardust@home and Galaxy Zoo launched, allowing interested people to trawl through images in order to do things like identify interstellar-dust impacts or classify galaxies. Isaac joined their ranks around the same time and has been enabling citizen scientists to find asteroids ever since.

Grab a buddy or two. Your starting point for all things asteroid-hunting is the Isaac website: **iasc.cosmosearch.org**. But before you get too deep into the nuts and bolts, find an observing buddy (or two) — Isaac requires that interested parties register as teams. Next, use your imagination to drum up a name for your team; make it fun (but relevant!). After you've registered your team on the website, you'll receive an email with all you need to know regarding upcoming campaigns. Isaac structures these as four-week-long endeavors.

There's one more step before you can start searching, and that is to download the software for the data analysis, *Astrometrica*. You'll find it under a tab at the top of the Isaac homepage; note that it's incompatible with Macs. While you're waiting for the campaign to start, it behooves you and your teammate(s) to familiarize yourselves with the software. During each campaign, new data (usually from one of the two Pan-STARRS telescopes atop Haleakalā on Maui in Hawai'i) are delivered regularly via email, and teams can then visually inspect images using *Astrometrica*.



▲ **MOVING TARGET** The sequence above shows the discovery images of 2020 SS_{13}, obtained with the University of Hawai'i's Pan-STARRS1 telescope. The interval between the two frames is approximately one hour; you can distinctly see the object moving against the background stars.

PRANVERA HYSENI / HAP GRIFFIN / INSTITUTE FOR ASTRONOMY / UNIVERSITY OF HAWAI'I / PAN-STARRS PROJECT OFFICE (2)

Ready? Search! You have your observing partner(s), you're a pro with the software, and you have the data — now all you need to do is start searching. You can follow in the footsteps of outreach ambassador and graduate student Pranvera Hyseni (University of California, Santa Cruz) and prolific amateur Hap Griffin, who teamed up under the moniker ImagingInfinity. Hyseni says that getting involved in Isaac was a "great opportunity, and the fact that you can find objects that no one has seen before adds an element of thrill."

And this they did. While trawling through data in the spring of 2020, they identified an object that moved in several consecutive images. After carefully crosschecking existing databases, they realized they'd struck paydirt: a 25th-magnitude object, which was later provisionally dubbed 2020 SS_{13}.

Hyseni and Griffin submitted the orbital data of 2020 SS_{13} to the Minor Planet Center (**minorplanetcenter.net**) and are now awaiting verification. It can take some three to five years for the MPC to confirm detections, so be patient with your own discoveries! In the meantime, you can find the target info for Isaac detections in the MPC or Jet Propulsion Laboratory (**jpl.nasa.gov**) databases.

"JPL has generated an interactive map of 2020 SS_{13}'s location, which shows that the next near approach will be in the late autumn of 2024," says Griffin. "It was extremely exciting to know that once it's recovered at or very near the coordinates predicted by our observations, it will be confirmed as a new asteroid, and we'll get the honor of naming it." They'll use the prefix "AOK," which stands for Astronomy Outreach of Kosovo, an organization that Hyseni (and collaborators) founded in 2015 to build the country's first observatory and planetarium.

One of the great things about Isaac is that you really don't need any equipment to participate. "The project gives the opportunity for everyone to engage," says Hyseni. "It's all about the general public gaining new skills, learning how to use the software, and ultimately contributing to science."

Who knows, maybe you'll discover the next asteroid that buzzes Earth.

■ Observing Editor **DIANA HANNIKAINEN** applauds projects that give everyone the opportunity to participate in astronomy.

ALL SKETCHES BY HOWARD BANICH

Messier 33
An Observer's Guide

Get the best out of this wonderfully detailed spiral galaxy.

In which face-on spiral galaxy can you see spiral arms, H II regions, stellar associations, globular clusters, patches of dark interstellar gas and dust, and maybe even a couple of its brighter stars? And all this without needing a monster telescope to boot?

From the Northern Hemisphere, look no further than **M33**. Famous for both its remarkable wealth of galactic detail and its visual subtlety, the Triangulum Galaxy, for far too many observers, is equally infamous for being effectively invisible. Minimal light pollution or a slightly hazy sky can mask or completely hide the wonders of M33. But the good news is that even a small scope can show a lot of satisfying structure under an unspoiled, dark sky.

How small? An 80-mm will do for a start. But as is usually the case, the bigger the scope and the better the sky, the more you'll see. But don't let less-than-optimal sky conditions stop you from having a look.

I made sketches of M33 while observing with my 28-inch scope between 2009 and 2013 and with my 30-inch in 2022. I also sketched it with 8-inch and 80-mm scopes on the same nights I used the 30-inch. Each instrument gave memorable views, and even though I'm partial to what I saw in the 28- and 30-inch, I was rather amazed at how much I detected in the smaller apertures. But then, M33 is rather nearby as galaxies go.

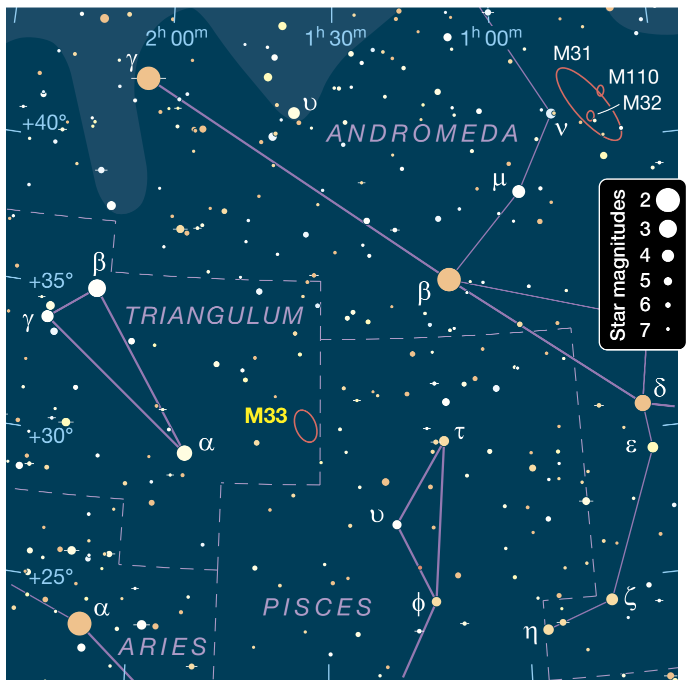
◀ **M33 IN ALL ITS GLORY** This sketch illustrates how M33 appeared through my 30-inch f/2.73 alt-az Newtonian. This view approximates what I observed at 140× over seven nights in 2022 and highlights all the objects discussed in the text — and many more. It requires clear, dark, and transparent skies to see this much even in a large telescope, but much smaller instruments can nevertheless capture remarkable detail. Aside from spiral arms and dark nebulae, you can observe H II regions, stellar associations, clusters, and even individual stars in M33. North is up in all images unless otherwise noted.

▶ **IN THE TRIANGLE** M33 is located close to the western boundary of the tiny constellation Triangulum, from which it gets its common name. You should find the galaxy quite readily a bit more than 4° west-northwest of 3.4-magnitude Alpha (α) Trianguli. On nights with excellent observing conditions, you might even see it without optical aid.

To my surprise, we still don't know exactly how far away the Triangulum Galaxy is. Based on different methods of measurement, distance estimates have ranged from 2.2 to 3.2 million light-years. Most recent studies place it in the middle of this range, indicating that it's approximately 2.8 million light-years from us.

M33 may be a gravitational companion to M31, the Andromeda Galaxy, and studies place it as far away as some 770,000 light-years from M31. The Triangulum spiral is also the third-largest member of the Local Group (after M31 and the Milky Way), and at 60,000 light-years in diameter, it's a bit more than half the size of our galaxy.

It's classified as an SA(s)cd galaxy, where SA denotes it's an ordinary spiral galaxy without a central bar; the (s) indicates it has prominent S-shape arms emanating from its central core; and the cd means the spiral arms are loosely wrapped. That's a pretty good overall description of M33, but it really



only hints at all the delights that the galaxy has to offer the observer.

When I observe M33, or any deep-sky object for that matter, as I get to increasingly dark and transparent skies I feel as if I'm peeling away layers of atmosphere and light pollution. I also envision ever larger telescopes adding layers of detail. Let's explore all this and more in the next sections.

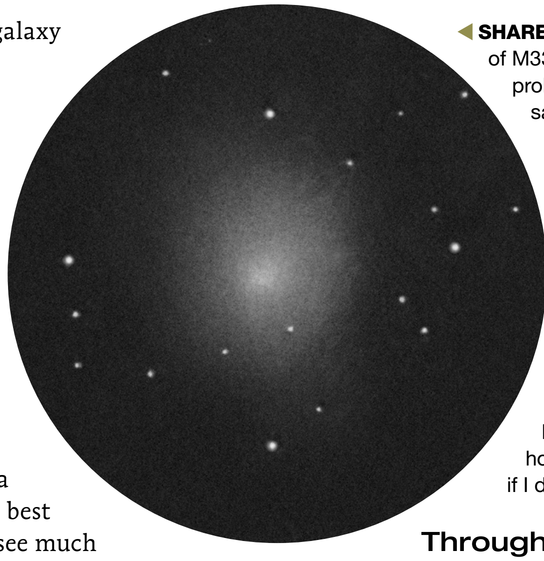
General Observing Tips

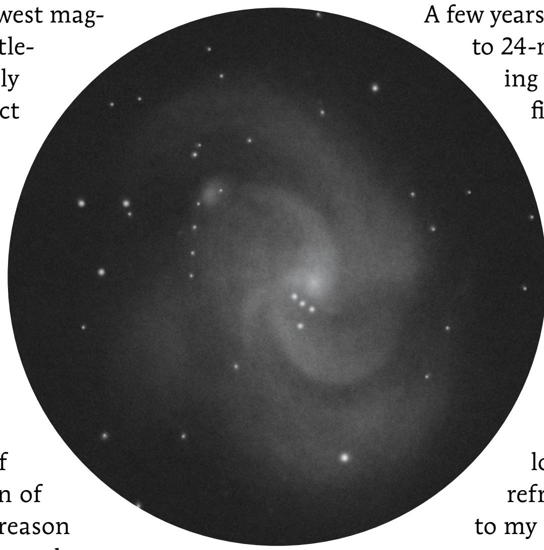
Due to its relative proximity, M33 has a large apparent diameter, yet it's a delicate thing visually. Even under the best observing conditions, don't expect to see much at first. I suggest starting with your lowest magnification and then linger. Let the subtleties of the Triangulum Galaxy gradually reveal themselves as you use both direct and averted vision. If you can, sketch what you see. Then increase the magnification to your next most powerful eyepiece. Add any new details to your sketch — or memory — and repeat this cycle with your eyepieces until you can no longer discern further nuances.

Next, go back to the eyepiece that gave you the most pleasing overall view and absorb the gentle glory of this fascinating galaxy. This collection of around 40 billion stars is part of the reason M33 seems so ephemeral. Because it's so close by and we view it mostly face-on, we can see many of the elements that make up a typical spiral galaxy — but we're also looking through its thinnest dimension. So, our viewing angle, combined with the relative paucity of stars in M33 (less than half and maybe as few as one-tenth the Milky Way's number), gives it a low surface brightness. Nonetheless, in a dark, transparent sky you can expect to see wonderful things.

If you can detect 5.7-magnitude M33 naked-eye from your observing site, you're in for a treat once you start using your telescope. In my experience, seeing the Triangulum naked-eye means the sky is not only dark but also very transparent. The ease or difficulty in viewing it without optical aid is a good way to gauge observing conditions.

On a few occasions, M33 has jumped out with direct vision when I glanced up at its location in Triangulum, but I usually need to use averted vision to detect it. Sometimes it's invisible no matter how long I try to fish it out of what seems like an excellent sky — that's a clue that atmospheric transparency isn't as good as it might initially seem.





◀ **SHARED VIEWS** *Top:* This drawing depicts the view of M33 through my 80-mm finderscope — and is probably quite similar to what Charles Messier saw when he first sighted the galaxy. Neither he nor I saw spiral structure, but the general glow of M33 was a direct-vision sight.

◀ **DETAILS EMERGE** *Bottom:* The sketch shows how I saw M33 through my 8-inch f/3.3 scope — holy cow, I'm amazed at how much I could see! Compare this drawing to the one made with the 30-inch scope (on page 58), and although most of the details in that sketch aren't visible here, the overall spiral structure is spectacular. Notice near the end of the northern spiral arm how prominent the H II region NGC 604 is, even if I didn't mention it in my observing notes.

Through the Finderscope

A few years ago, I added a zoom eyepiece (8-mm to 24-mm) to my 80-mm finder. By modifying the magnification I can use the 80-mm finderscope as a regular telescope.

From my moderately light-polluted backyard and with direct vision, M33 through the 80-mm looks like a rather large and subtle oval mist with indistinct edges. There are a few field stars scattered around it, and the inner portion of the galaxy is slightly brighter than the rest.

As it turns out, my view is similar to what Charles Messier saw when he logged M33 in 1764 with a 3-inch f/4 refractor, an instrument nearly identical to my finder. Here are his notes:

> *The nebula is of a whitish light of almost even density [of brightness], however a little brighter along two-third [sic] of its diameter, & contains no star. One sees it with difficulty with an ordinary telescope of 1-foot [FL].*

In fact, it seems that Messier wasn't the first to view M33 in a telescope. It turns out that Giovanni Battista Hodierna was probably the first to see it using a Galilean refractor at 20× sometime before 1654.

In my finderscope under a dark sky, Messier's "whitish light" is bright and obvious, as I noted:

> *This is a fun view to sketch — M33 as seen through my 80-mm finder! M33 looks like an oval smudge, slightly brighter in its center, and with indefinite perimeter that fades imperceptibly into the dark. I can't see any trace of the spiral arms, even with the zoom eyepiece cranked up to full magnification (37.5×).*
>
> *M33 is set in a lovely star field and (is within) a quadrangle of stars that are the brightest in the FOV. Beautiful! 21.37 SQM.*

As I've had many nights when I couldn't detect M33 because the sky was too bright or it was otherwise impenetrable, I remember really enjoying this view.

From 8-inch to 30-inch Scopes

With an 8-inch scope in a light-polluted sky, M33 often looks much like it does in the 80-mm finder under a dark sky. When I was a novice observer with my 8-inch f/4 scope, that was enough to get me excited.

Now, and under a much darker sky with my 8-inch f/3.3 telescope, M33's spiral form is dramatically obvious — much more so than M51's spiral arms in the same instrument. To me, this is where the Triangulum Galaxy becomes really interesting. Well-known observer Stephen James O'Meara has seen the spiral arms of M33 with a 4-inch refractor, which is another indication that the spiral arms are rather prominent if you observe with a widefield instrument in dark, transparent conditions.

My observing notes from August 2022 with my 8-inch f/3.3 state:

> *I'm amazed at how much detail I can see through the 8-inch! Not only are the three main arms visible but so are the two long extensions — I had no idea I could see this much with this scope. I can't help but remember how many years it took me to even detect M33's presence when I was a kid. 95×, 21.77 SQM*

I started my first sketching project of M33 with my 28-inch f/4 scope in 2009. I waited for the very best nights to add new details to my sketch, so it took me about four years to feel that I'd captured M33 well.

▲ **TRIANGULUM'S GEM** The National Science Foundation's 0.9-meter telescope on Kitt Peak captured this image of M33. Star-forming regions appear reddish, while hot young stars lend the galaxy its bluish hue.

T. A. RECTOR (NRAO / AUI / NSF AND NOIRLAB / NSF / AURA) AND M. HANNA (NOIRLAB / NSF / AURA)

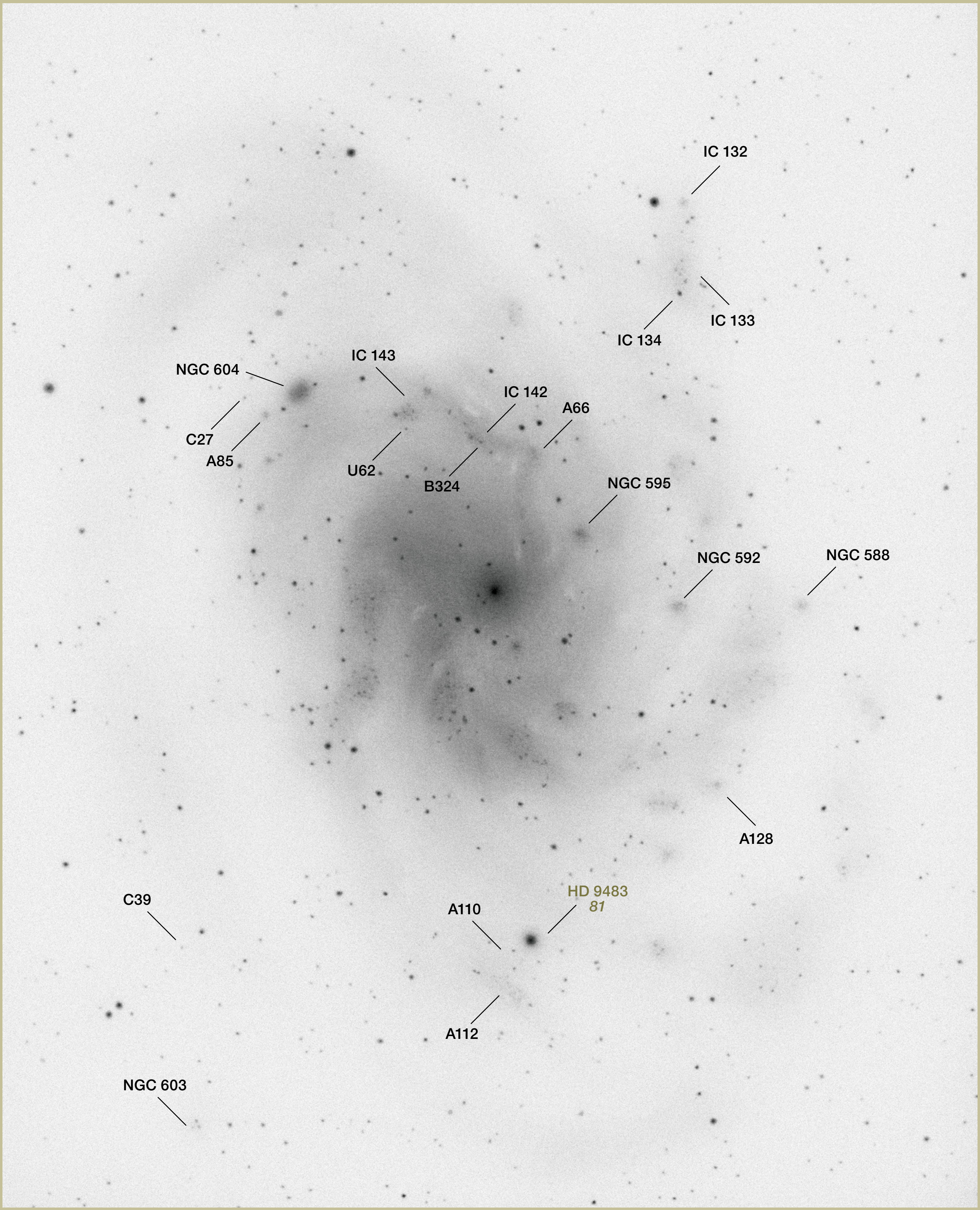
Spiral Speculation

If we're detecting M33's spiral structure in smaller scopes, it begs the historical question: Why didn't the Herschels see the spiral arms in their 18.7-inch (f/12.8) scopes? For that matter, why didn't William Parsons, the Third Earl of Rosse, espy them with his 36-inch (f/8.7) reflector? My goodness, it took his 72-inch (f/9) reflector for him to discern M33's spiral nature! And it's not because the 18.7-inch and 36-inch telescopes didn't have enough light-gathering power, even though their speculum-metal mirrors were at best only about 65% reflective.

Part of the reason is that these fabulous observers were intent on resolving M33 into stars, which the Herschels and Lord Rosse felt they had partially done. Deep-sky visual observers today have different observing goals for what we now know to be a spiral galaxy — but both then and now, perceiving what we hope to see is a powerful bias that's difficult to overcome.

Still, it seems there's more going on than observational goals and biases, because in a good sky the spiral structure of M33 is so beautifully apparent in a modern 8-inch rich-field scope. Another possibility is that M33's spiral arms were difficult to see because the true fields of view through these 19th-century long-focus telescopes were so much narrower than what we enjoy today, and M33 just didn't fit into one eyepiece view. Plus, these huge telescopes were unwieldy for panning around a large object.

So why was the spiral structure first seen in the 72-inch, which would have had the smallest true field of these old telescopes? Lord Rosse discovered M51's spiral structure in 1845, and he soon revamped his observing program for the big scope to look for more "spiral nebulae." Five years later he saw M33's spiral arms. We really do tend to see what we're looking for.



A FEAST FOR THE EYE All the objects mentioned in the text are labeled in this negative version of the sketch made with the 30-inch scope.

Then, last year I sold the 28-inch optics and replaced them with a 30-inch f/2.73 meniscus mirror. I modified the structure of the 28-inch to fit the new optics, and I now have a scope with a significantly wider true field of view — so I just *had* to sketch M33 all over again. I started with a preliminary rendering one night when it was too spectacular to ignore:

> *Oh my goodness, M33 is so BIG! The usually difficult to see outer spiral arms are surprisingly distinct and easy to follow as they wrap around the galaxy. [My] rough sketch [is] mostly to show the extant and width of these arms. 140× gives the best view. 21.65 SQM*

That was a great night, and I had several more in the late summer of 2022, but I saw way too much in M33 to describe it all. Instead, here are some of my favorite highlights.

Spiral Arms

The northern and southern spiral arms form the backbone S of M33's spiral arms and dominate the overall structure of the galaxy. The northern arm is the most prominent and curves northward like a crooked finger from the core region. About halfway along its extent, there's a noticeable kink, which reminds me of the sharp bend in M51's northern spiral arm. You may have to look for it carefully because it can get lost with everything else going on. It's possible this kink is a result of M33's *flocculent* (having multiple arms) spiral structure forming and reforming over time.

The main southern spiral arm is punctuated with three large star clouds that originate from what may be a very short central bar near the origin of the much shorter eastern spiral arm. But then, the appearance of this area may just be where these two arms meet the core. A recent study by astronomers using the Hubble Space Telescope showed that stars older than one billion years might actually form a central bar that's masked by the distribution of younger stars. Did I see some of that older-population bar? Probably not, because what I saw is much shorter than what would constitute a central bar.

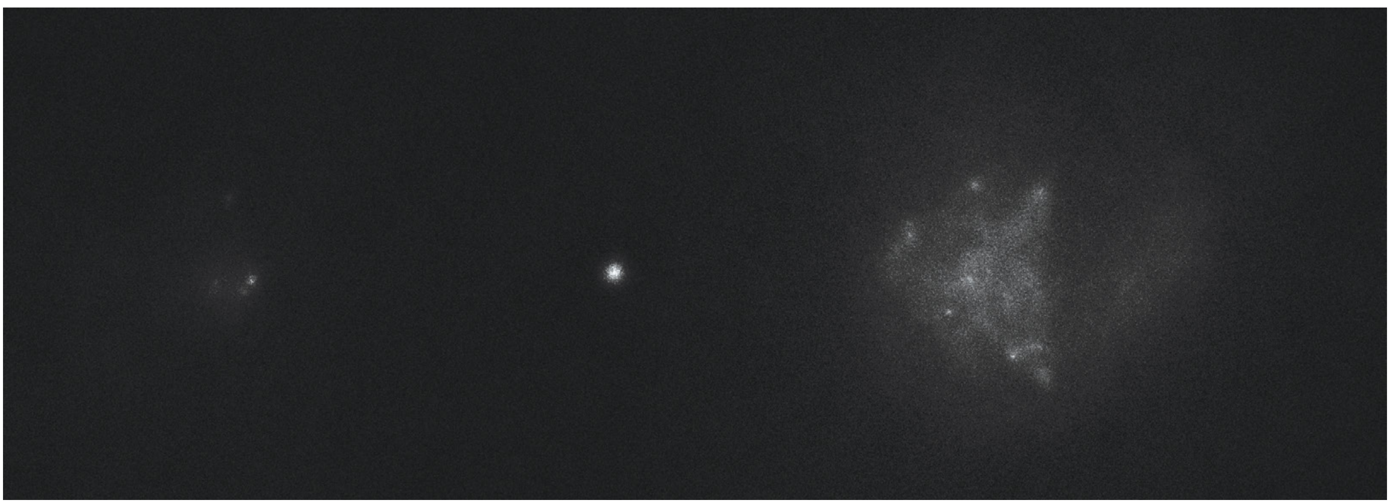
There are faint extensions of the northern, southern, and eastern arms that continue wrapping around M33 as well as several equally faint features that seem only casually connected to the main arms. I noted arm segments as well, but seeing any of them is very much dependent on observing conditions and the size of your telescope.

Several areas of dark gas and dust lanes underline the shape of M33's arms, with the most prominent ones being where the northern spiral meets the core. Just about as visible is a small, dark patch on the inside bend in the kink of the northern arm. There are many more scattered throughout the galaxy, but they're generally fairly diffuse.

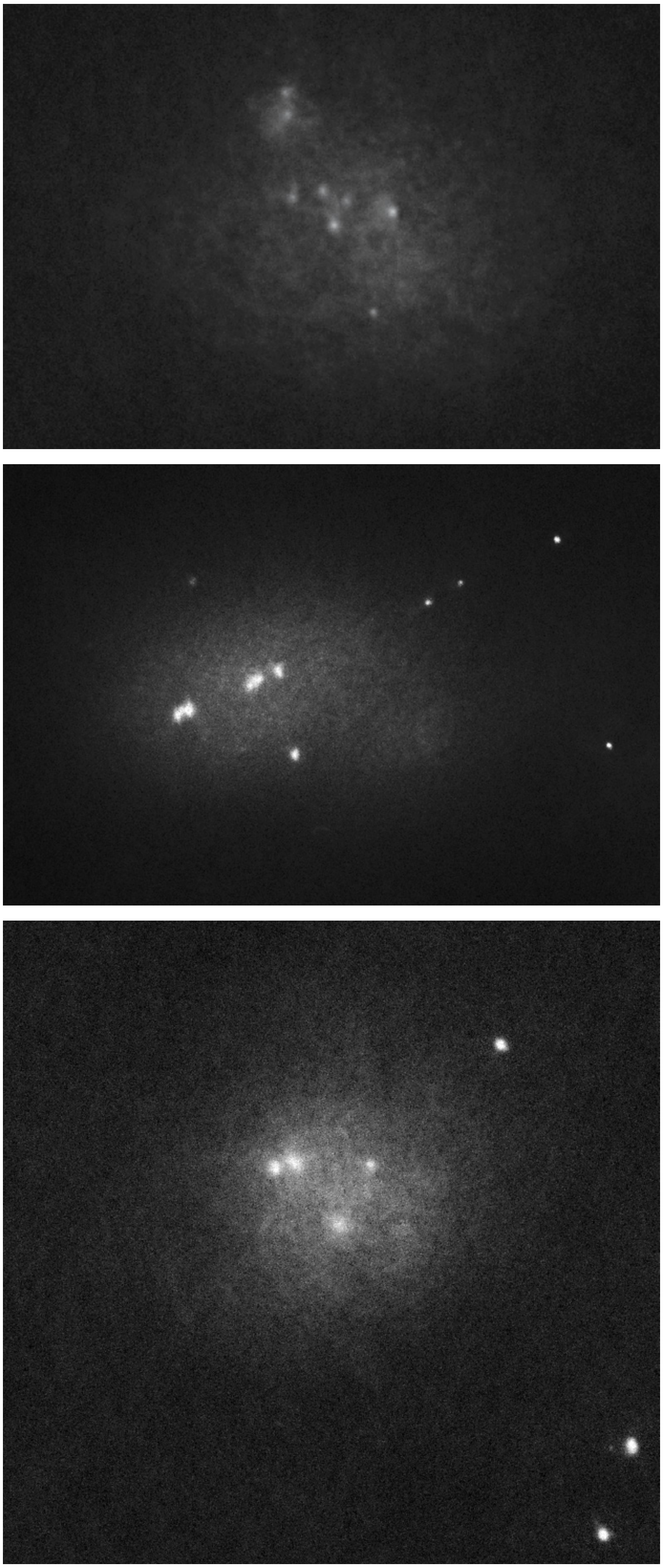
The Many Marvels of M33

In a fairly large amateur scope, an observer can detect most of these internal details: H II regions, stellar associations (collections of OB stars in star-forming regions), and even a smattering of globular clusters. Some telescopes show significant structure at high magnification on nights with steady seeing and even reveal a couple of M33's brightest individual stars. This galaxy is absolutely loaded with stuff to observe if you have a dark enough sky and a scope 8 inches or larger.

Foremost is **NGC 604**, a star-forming H II region so large that it displays a wonderful irregular shape at high power. It's about 1,500 light-years in *diameter,* which is also about how far away we are from the Great Orion Nebula in our own galaxy — imagine a star-forming region that stretches from here to M42! NGC 604 and the galaxy's core are M33's brightest features.



▲ **DIVERSE NEBULOSITIES** NGC 604 is on the right side of this sketch as I saw it through my 28-inch scope at 695×. I usually perceive this H II region as two overlapping triangles of nebulosity, and on the best nights I see a stubby tail. The faint stars within NGC 604 are huge *O* and Wolf-Rayet stars. The stellar association A85 is at left in the sketch. The star between the two nebulae is 11.0-magnitude TYC 2293-642-1, and just outside the upper left of this closeup is the globular cluster C27. North is to the upper right.



▲ **MORE THAN JUST BLOTCHES** Lined up from top to bottom are NGC 595, NGC 592, and NGC 588. I made these close-up sketches using the 28-inch scope at 695×, and they show that these H II regions are more than tiny smudges. With steady seeing and a large amateur scope, these objects show interesting details.

It takes steady seeing to see detail within NGC 604, and I've had only a few nights when this was possible. I could even detect a handful of the more than 200 huge O and Wolf-Rayet stars inside the nebula. At high power NGC 604 looks like two fuzzy, overlapping triangles with a few associated wisps. I tried an O III filter to enhance the nebulosity, but the unfiltered view was more pleasing.

Just southeast of NGC 604 is the stellar association **A85**. The 16.5-magnitude, starlike globular cluster **C27** is about the same distance northeast of A85. The brightest globular cluster in M33 is 16.1-magnitude **C39**, another starlike object, which is located in the southeastern outskirts of M33.

Three H II regions on the western side of M33 are conspicuous enough to merit NGC numbers: **NGC 595**, **NGC 592**, and **NGC 588**. Arrayed in a highly flattened triangle, NGC 595 is closest to M33's core, with NGC 592 and NGC 588 extending along a curved line westward. Goodness, these four NGC objects are star-forming regions in another galaxy, and not only do they take magnification well, they're also great fun to observe!

A fifth NGC object, **NGC 603**, is actually a nifty triple star that looks fuzzy at low power and is located south of C39, far out in the southeastern quadrant of M33.

At the northwestern edge of the galaxy, the group of H II regions and stellar associations cataloged **IC 132**, **IC 133**, and **IC 134** also show fascinating detail. Slewing to the southern outskirts of the galaxy, my two favorites are **A112** and **A110** because they're right next to the 8th-magnitude foreground star HD 9483, making them a good test for sky transparency. On a good night, big scopes show these (and many other) stellar associations sprinkled with tiny starlike objects. The stellar association **A66** resides at the kink of the northern arm, helping to define the arm's shape.

M33's brightest star is 15th-magnitude **B324**. It's situated within the northeastern end of the H II region **IC 142**, making it fairly easy to locate. **IC 143** is in the same high-power field of view, and the 17.2-magnitude globular cluster **U62** is right on IC 143's southern edge. You'll need a large telescope and steady skies to see this one well, and at best it will appear starlike.

And on and on — almost every object in M33 has another one near it, and on a good night it seems that the galaxy is made up entirely of exquisite details. It's easy to lose track unless you're paying close attention, so a good finder chart is essential. (For starters you can use my sketch on page 62 or refer to sources listed in Further Reading.)

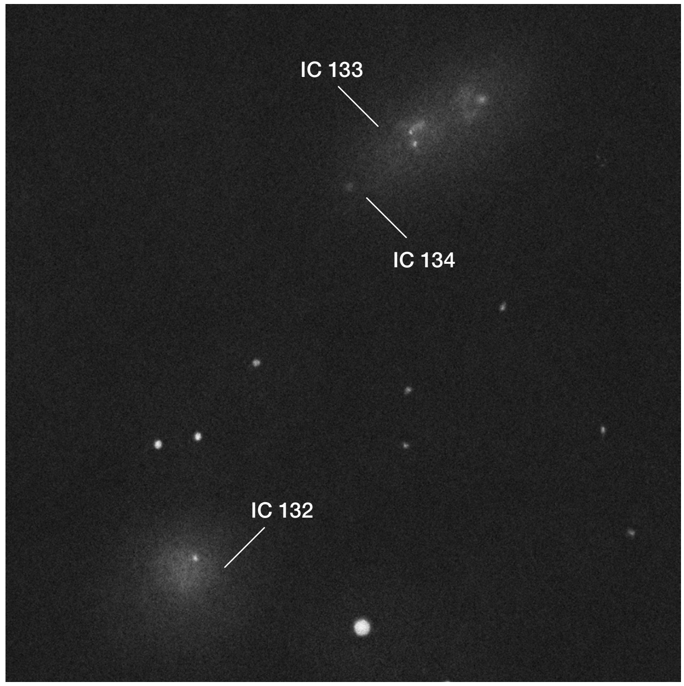
One thing you can't see in M33 is a supermassive black hole at its center. Not only because it would be hidden in the core, but mostly because it doesn't appear to exist. It seems that all galaxies probably have a supermassive black hole in their respective cores, but perhaps M33 is an exception that proves the rule. A study using the Hubble has placed an upper limit of a possible black hole in M33's core at 1,500 times the mass of our Sun, but the best fit to the data results in no black hole at all.

Supporting the Hubble finding, the dynamics of the stars in M33's core invoke more a huge globular cluster than a normal galactic nucleus, which may be another clue about what may, or may not, lurk there. Which would be more remarkable — a relatively tiny black hole or none at all? Contemplating this while observing M33 with your own telescope adds a final layer of wonder, because sometimes knowing something about what we see, or don't see, is the best part of it all.

■ By happy coincidence, this is Contributing Editor **HOWARD BANICH**'s 33rd article for *Sky & Telescope*. You can reach him at **hbanich@gmail.com**.

FURTHER READING: Several *Sky & Telescope* contributing editors have covered M33 in the past: Alan Whitman wrote about the galaxy in the December 2004 issue of the magazine, as did Ted Forte in the December 2013 issue. Steve Gottlieb's meticulously annotated chart of M33, along with extensive notes, is at **https://is.gd/M33_annotated**.

See Figure 2 in Roberta Humphreys' and Allan Sandage's 1980 article (**https://is.gd/Humphreys_Sandage**) for the location of stellar associations. Carol Christian's and Robert Schommer's 1982 paper will guide you to the positions of star clusters (**https://is.gd/Christian_Schommer**).



▲ **TRIO OF H II REGIONS** IC 132, IC 133, and IC 134 seem like a disconnected section of M33 through my 28-inch scope at 695×, but in the best conditions I see them as a bright area in the outermost northern spiral arm. North is to the upper right.

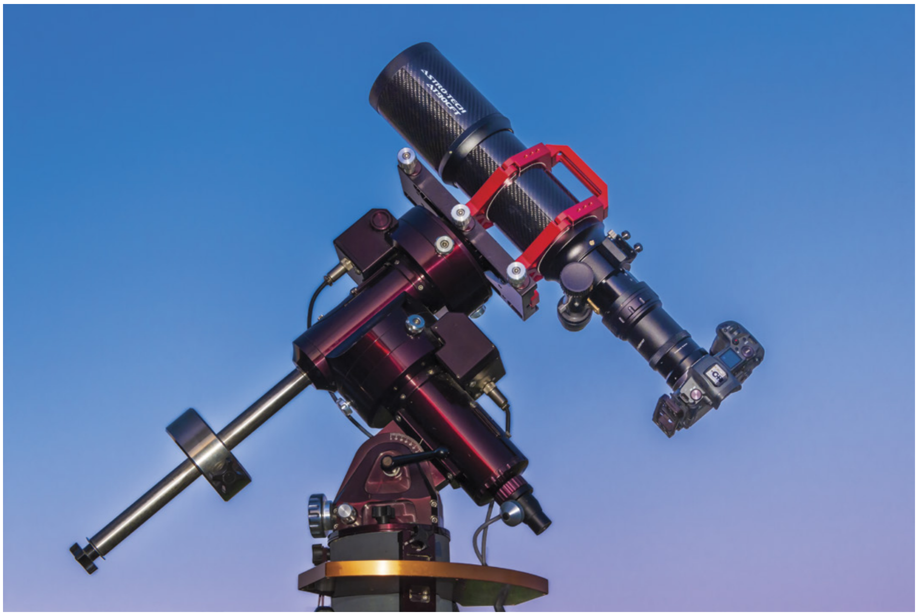
The Many Marvels of M33

Object	Type	Magnitude	Size/Sep	RA	Dec.
M33	Spiral galaxy	5.7	71′ × 42′	$01^h\ 33.8^m$	+30° 40′
NGC 604	H II region	12.0	1.0′ × 0.7′	$01^h\ 34.5^m$	+30° 47′
A85	Stellar association	16.8	—	$01^h\ 34.7^m$	+30° 46′
C27	Globular cluster	16.5	—	$01^h\ 34.8^m$	+30° 47′
C39	Globular cluster	16.1	—	$01^h\ 34.8^m$	+30° 22′
NGC 595	H II region	13.5	0.7′ × 0.5′	$01^h\ 33.6^m$	+30° 42′
NGC 592	H II region	13.0	0.8′ × 0.7′	$01^h\ 33.2^m$	+30° 39′
NGC 588	H II region	13.5	0.5′	$01^h\ 32.8^m$	+30° 39′
NGC 603	Triple star	—	—	$01^h\ 34.7^m$	+30° 14′
IC 132	H II region	13.5	0.8′ × 0.6′	$01^h\ 33.3^m$	+30° 57′
IC 133	H II region	14.0	0.4′	$01^h\ 33.3^m$	+30° 53′
IC 134	H II region	—	—	$01^h\ 33.8^m$	+30° 53′
A112	Stellar association	18.8	—	$01^h\ 33.7^m$	+30° 21′
A110	Stellar association	14.5	—	$01^h\ 33.7^m$	+30° 22′
A66	Stellar association	—	—	$01^h\ 33.8^m$	+30° 45′
B324	Star	15.2	—	$01^h\ 33.9^m$	+30° 46′
IC 142	H II region	14.2	0.5′	$01^h\ 33.9^m$	+30° 45′
IC 143	H II region	13.7	0.3′	$01^h\ 34.2^m$	+30° 47′
U62	Globular cluster	17.2	—	$01^h\ 34.2^m$	+30° 46′

Angular sizes are from recent catalogs and journal articles. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

The Astro-Tech AT90CFT

This apochromatic refractor provides excellent image quality in an attractive carbon-fiber tube.



▲ The AT90CFT weighs 5.8 kilograms (12.8 lbs) with rings, 0.8× Reducer/Field Flattener, and Canon camera as shown, making the author's Astro-Physics Mach1 mount overkill for an imaging setup.

AT90CFT f/6 Triplet APO Refractor

U.S. Price: $1,595
astronomics.com

What We Like

Sharp optics, excellent color correction

Attractive finish and fittings

Solid and precise focuser

What We Don't Like

Minor off-axis aberrations with 0.8x Reducer

Unnecessary locking screws on visual back

Short dew shield

NORTH AMERICAN TELESCOPE dealer Astronomics has introduced a new apochromatic refractor to compete in a crowded field of compact, photographically fast astrographs. Its house-branded Astro-Tech AT90CFT is a 90-mm f/6 triplet that has a stylish carbon-fiber tube, which is why it bears the CFT designation. That and the red anodized tube rings, dovetail bar, and top handle help the AT90CFT stand out from the pack, if only for its striking visual appeal.

But does this attractive instrument perform as good as it looks? I tested an early production sample sent by Astronomics (serial #00102) and put it through its paces for visual and photographic use, the latter with the optional Astro-Tech 0.8× Reducer/Field Flattener.

Big Shoes to Fill

In the March 2009 issue of *Sky & Telescope*, I tested an earlier 90-mm-class apochromat from Astronomics: the Signature Series TMB-92 with its unusually fast f/5.5 triplet lens designed by Thomas M. Back. The compact TMB-92 remained one of my favorite telescopes for many years, with its premium performance hampered only by the lack of a dedicated field flattener for imaging. The TMB Signature Series refractors are long gone, and I sold mine a couple of years ago. Astronomics promotes its new AT90CFT as the successor to the now classic and collectible TMB-92.

At an attractive price, too. The new AT90CFT retails for $1,595, though the optional Reducer/Field Flattener costs an additional $199.95.

Unlike the TMB, the Astro-Tech 90 mm isn't quite as prestigious or unique. The AT90CFT is similar to several other 90-mm apos currently on the market and sold around the world under various house brands. However, the lookalike scopes all have differences in either finish, tube materials, or the glass type used in the objective lenses.

In Astro-Tech's version, one of the elements in its 90-mm triplet objective is made of FCD-100 ED, a low-dispersion glass from Hoya in Japan that's equivalent to Ohara's FPL-53, a premium glass used for many top-class apo refractors. Does the Hoya glass perform as well?

Visual Performance

Yes, it does. There was no chromatic aberration (in the form of a blue or purple halo) visible around Venus or bright stars, both in-focus and when I racked through focus. Extra-focal star images looked colorless.

A Strehl ratio of at least 0.95 is promised for all units, with 1.0 being perfect (possible only in theory), and anything above 0.8 deemed ¼-wave "diffraction limited."

While some of the lookalike 90-mm telescopes from other brands come with individual test certificates measuring that unit's optical performance, the Astro-Tech model does not. This avoids the potential for "Strehl-ratio

ALL IMAGES COURTESY OF THE AUTHOR

envy" among buyers, as someone with a "mere" 0.95 unit is unhappy with their purchase because a friend has a 0.97 unit.

Not having a laser interferometer on hand, I was unable to test the Strehl claim for my sample, but a star test can reveal even the slightest aberrations, and the AT90CFT certainly passed handily. The telescope showed only the barest trace of spherical aberration, but no astigmatism from pinched or misshapen optics. Star images in focus were textbook-perfect.

Even without a performance certificate, this is a telescope that should please even the most discerning apo lover. It offers color correction a cut above many of the competing telescopes in this aperture class that use lesser and often undisclosed types of glass.

Photographic Performance

As I would expect based on the telescope's visual performance, there was no sign of longitudinal chromatic aberration adding blue halos to stars in long-exposure photos, even when using the 0.8× Reducer/Field Flattener yielding a focal length of 432 mm at f/4.8. The reducer requires 55 mm of back focus; I tested it most nights with a filter-modified Canon R mirrorless camera and specialized T-ring that provided precisely that spacing.

With the Canon's full-frame (36-by-24-mm) sensor, images did show what looked like slight coma and some lateral chromatic aberration (colored streaks) at the extreme corners of the frame. The aberration-free imaging circle proved to be about 32 mm in diameter, certainly very good, but not perfect for those who like to pixel-peep. However, I've rarely seen apo/reducer combinations that don't exhibit some corner aberrations. The old TMB-92 used with a generic reducer was much worse.

The AT90CFT is certainly capable of superb images with full-frame cameras. As useful and essential as the 0.8× Reducer/Field Flattener is for deep-sky imaging, I would like to see Astronomics also offer a 1× field flattener for this telescope. That would provide even more flexibility for framing targets at the telescope's native focal length of 540 mm, while retaining the relatively fast speed of f/6.

Mechanical Quality

The telescope's fittings are first-class, with beautifully machined tube rings and a 2.5-inch rack-and-pinion focuser with a 10:1 fine-focus motion. The focuser allowed precise adjustments with no backlash and did not slip when carrying a heavy load even when unlocked and aimed up. It was a pleasure to use each night.

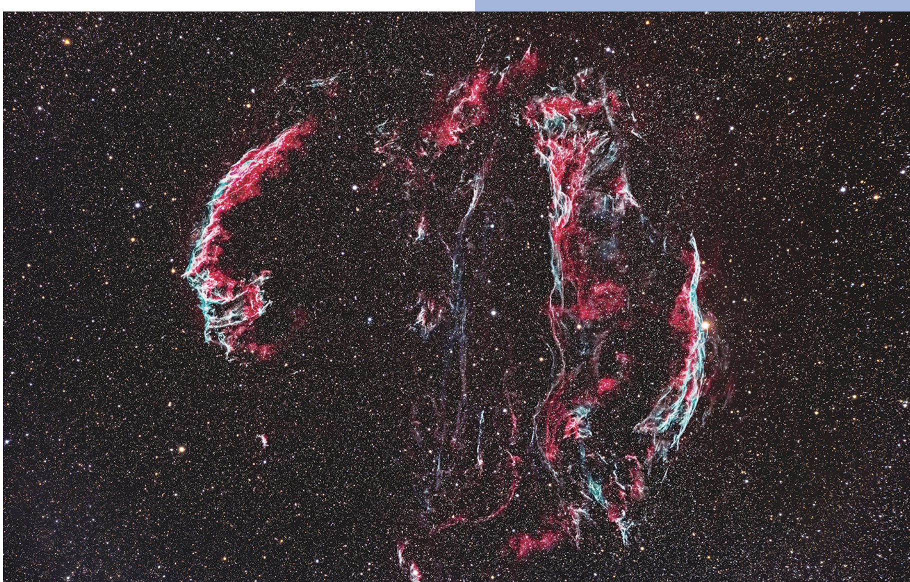
The entire focuser can rotate. However, out of the box I found I had to tighten the three slotted brass screws on the mechanism to eliminate some slop when the focuser's rotation lock knob was loosened. After that it worked consistently well.

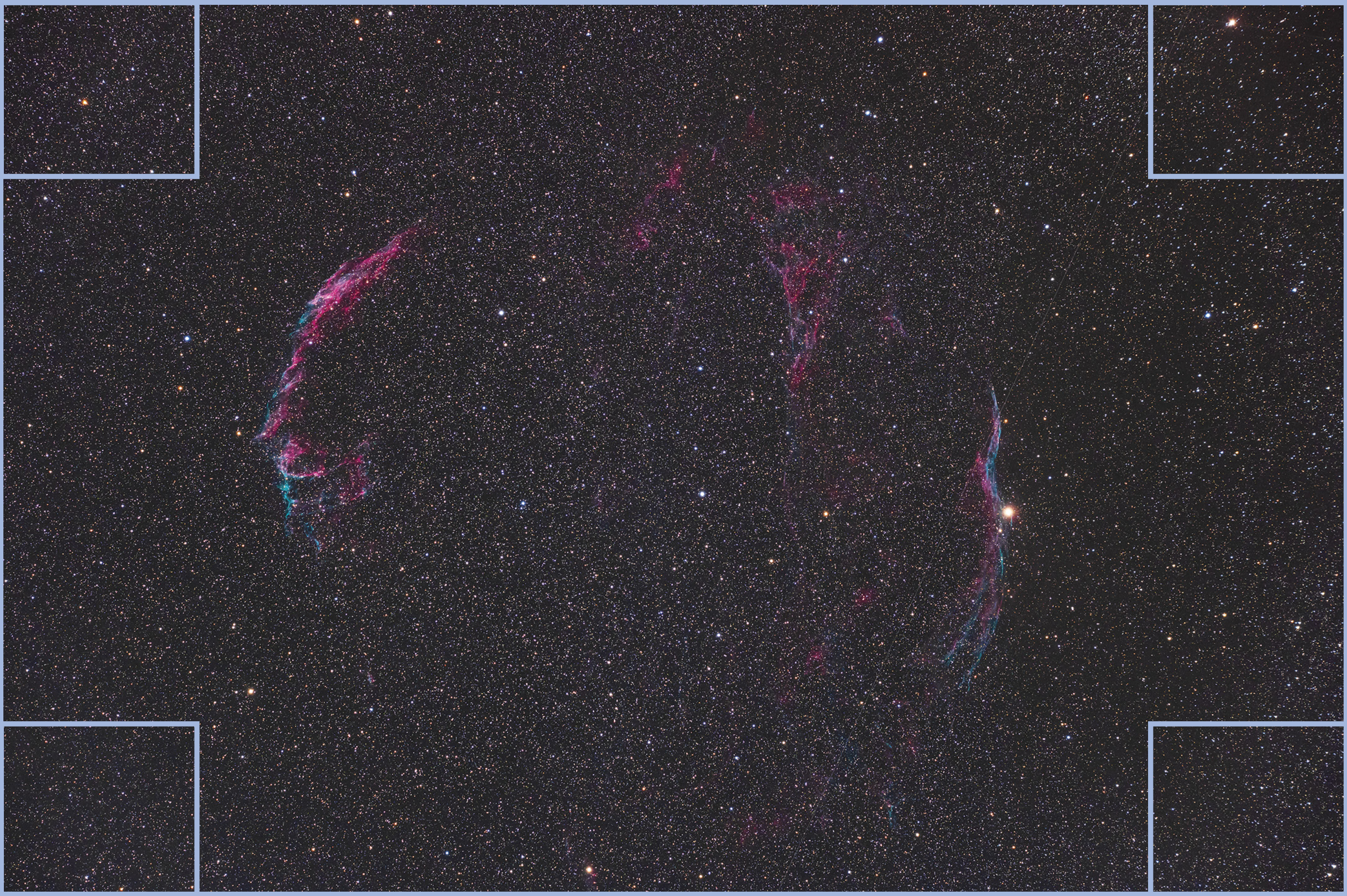
The separate camera-angle adjustment at the end of the focuser worked without issue, with no shift in image position or focus when turned, and no tilt to the plane of focus. This rotator remains attached to the focuser when using the included two-inch visual

▲ The telescope comes with red anodized tube rings, a 245-mm-long Vixen-standard dovetail bar, and a top handle. A 2-inch visual back with 1¼-inch adapter is standard, but the 0.8× Reducer/Field Flattener shown is a $200 option.

▲ The 90-mm triplet objective is fully multicoated, and the tube interior is well-blackened and fitted with two mid-tube baffles to suppress stray light. The focuser is also ribbed with a series of knife-edge baffles.

▼▶ The optional 0.8× Reducer/Field Flattener corrects the field and widens it to 4.7° by 3.2° with a full-frame sensor. The end ring accepts 2-inch filters in a conveniently accessible receptacle. Filters are useful for enhancing nebulae such as in this blend of narrowband-filtered and unfiltered images.





▲ Blow-ups of one of the unfiltered frames used in the final Veil Nebula image show the slight level of coma and lateral color present at the extreme corners of a full-frame sensor, in this case a modified Canon EOS R camera.

adapter to place a star diagonal at a convenient angle. It is a feature whose convenience I appreciated every night for both visual use and photography.

Unfortunately, the rotator has no angular degree markings to facilitate precise camera positioning for mosaics or multi-night shoots. However, its barrel includes millimeter markings for presetting the focus point.

The knobs for locking the focuser and camera rotator are both large and easy to adjust. The scope's slip-on front lens cap is metal and stayed on securely. But the screw-on end caps for the reducer are plastic, not quite in keeping with the telescope's other finely machined fittings.

The visual adapter came attached to the focuser but was tightly locked onto it with a trio of 1.5-mm hex screws, making it impossible to remove. Using my own hex wrench (none was supplied with my test unit), I backed off those hex screws so I could unscrew the visual back to swap it for the Reducer. The locking hex screws on the visual back seem unnecessary and a potential source of dismay to users wanting to use their new telescope the first night out for imaging.

The visual back accepts two-inch accessories and comes with a 1¼-inch step-down ring. The 2-inch adapter has a unique twist-lock clamp that is sufficient for holding a star diagonal and eyepiece in place with just a 30° turn, making it easy to quickly change accessories.

The telescope's two included tube rings are each drilled with a trio of M6-threaded holes on two faces, one on each side of the rings. But one side has the rings' large clamping knobs, great for adjusting the rings without tools but preventing anything else from attaching to that face of the rings, rendering those mounting holes unusable.

The top of the rings has a bolted-on bar that separates the rings by 105 mm and is drilled with a single ¼-20 and two M6 bolt holes for attaching other accessories. While useful as a handle, I would have preferred another Synta-standard dovetail shoe there, to complement the single finder shoe that is included on the focuser. This would offer a better location for a guidescope and autoguider.

▲ *Left:* The locking knobs for the focuser (left) and the camera angle adjuster (right) are large and easy to use with gloves on. The Reducer/Field Flattener has 48-mm threads on the camera side. *Right:* For balancing heavy cameras, the dovetail bar can be reversed to extend back another 60 mm from the position shown. The focuser is compatible with most focus motors.

The dew shield is 150 mm long but extends only 76 mm past the front objective. While certainly adequate, it's a pity the design doesn't allow more of the dew shield's full length to be used for the crucial task of keeping moisture and frost off the objective lens. The dew shield has a locking bolt, but even with it loose, the dew shield never slid back on its own when aimed up.

The carbon-fiber tube is the telescope's unique selling point. Carbon fiber saves weight and typically reduces focus shift arising from changes in tube length due to temperature. On cool spring nights I found I still had to wait the usual 30 minutes or so after bringing out the telescope from indoors, but that's more a function of the lens itself needing to reach thermal equilibrium before it performed at its best. After that initial cool-down, the telescope did maintain focus quite well.

The AT90CFT's tube with visual back, but no rings, weighs 3.6 kg (7.9 lbs), exactly the same as an aluminum-tubed Sharpstar 94EDPH refractor without its rings. So there is no advantage in weight. However, the carbon-fiber tube does have value in reducing focus shift. But it mostly just looks good. I think that's a worthy attribute that adds to the enjoyment of using any telescope.

Recommendations

I've often felt that if I had to give up all telescopes but one for visual and photo use, I'd choose a top-class 90-mm apo refractor. The AT90CFT would be a good candidate as a desert-island telescope.

After an initial night or two of testing, it was obvious there were no optical or mechanical issues with the scope. I just started using it to take the images I wanted, always a sign that a telescope has passed muster.

The AT90CFT makes an attractive combination with ZWO's red-trimmed AM5 or AM3 mounts. But I also used it on several nights with the less costly and lightweight Sky-Watcher EQM-35 mount, which also supported the Astro-Tech just fine. All three are good choices for pairing with this telescope, as are many other smaller equatorial mounts in the $1,000 to $1,500 price class.

After using the AT90CFT for a couple of months, I can conclude that it does indeed perform as well as the original TMB-92, if not better. Astro-Tech offers a dedicated field flattener for imaging with this gem — something the TMB lacked. Visually, the AT90CFT presents views at the eyepiece that can match the best glass on the market today.

I can certainly recommend the Astro-Tech AT90CFT to anyone looking for a premium, portable, affordable telescope for visual and photographic use. It's certainly a worthy successor to Thomas Back's classic Signature Series TMB-92.

■ Contributing Editor **ALAN DYER** is co-author with the late Terence Dickinson of *The Backyard Astronomer's Guide*. He can be reached through his website at **amazingsky.com**.

◀ SOLAR FINDER

Amateur Bob Schalck offers a low-cost, easy-to-use solar finder for virtually any telescope. The Sun Geometer ($19.95) is a laser-cut kit that projects a cross on a rear target. Simply move your telescope until the "auto-cross" is superimposed on the target face and the Sun will be in your safely filtered telescope's field of view. The Sun Geometer is made of lightweight wood, and its footing permits its installation on a wide range of optical tube assemblies with curved or flat surfaces. Shipping is free in the continental United States.

Bob Schalck
oceaniclaserworks@gmail.com

◀ AZ/EQ MOUNT

Mount manufacturer iOptron adds a new member to its family of strain-wave mounts. The HAE69 Dual AZ/EQ SWG Mount ($3,840) uses high-torque strain-wave drives in both axes to achieve precision slewing and tracking throughout the sky. The mount head weighs just 8.6 kg (19 lb) yet boasts a load capacity of 31 kg without the need for cumbersome counterweights and shafts. The HAE69 can be operated in either equatorial or alt-azimuth modes with 15 arcsecond periodic error over a 270-second gear cycle. It's controlled with the included Go2Nova hand controller or the *iOptron Commander Lite* app (available for Apple and Android devices) as well as other compatible third-party software and apps connected via its internal Wi-Fi. The mount accepts both Vixen- and Losmandy-style dovetail mounting plates. Each purchase includes an aluminum carry case and a limited two-year warranty.

iOptron
6F Gill St., Woburn, MA 01801
781-569-0200; ioptron.com

◀ BIG PLATE-SOLVING SCOPE

Celestron expands its line of smartphone-driven instruments with the addition of the StarSense Explorer 12″ Smartphone App-enabled Dobsonian Telescope ($1,499.95). This 12-inch, f/4.9 Newtonian reflector uses patented technology to offer precise navigation with the help of your smartphone. Simply install the *StarSense Explorer* app on your compatible Apple or Android device and place it in the telescope's smartphone docking port. The app (by the makers of *SkySafari*) will determine the exact location and direction that the telescope is pointing by analyzing short exposures with your phone's camera. It then identifies star patterns in its internal database, no matter where it's pointed in the sky. The telescope includes a red-dot finder, a 2-inch, 32-mm eyepiece, a 2-inch to 1¼-inch eyepiece adapter, a collimation tool, and StarSense smartphone dock. Requires devices with Android 7.1.2 and later or iPhone 6 and newer phones.

Celestron
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310-328-9560; celestron.com

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The Darkness Before the Dawn

Frustration is part of the process.

◀ To make the ball, I coated a kids' rubber ball in fiberglass. That was the hard way! It required hours and hours of sanding and patching to make it smooth and spherical.

IN THIS COLUMN I normally try to show people how easy and rewarding it can be to build your own astronomy equipment. In my very first column (*S&T:* June 2016, p. 68), I stressed how simple and fun it can be, and I've mostly stuck to that mantra ever since.

However, there's a dirty little secret lurking between the lines: Setbacks and frustration are also part of the process. And the more ambitious the project, the more frustrating it can be.

With that in mind, I want to tell you about my first telescope-making project.

My first scope build was my 10-inch trackball. That's right: Rather than learn on something straightforward and simple, I decided to build a ball scope and make it track. There were no models to work from, no plans on the Stellafane website, nothing. I had to make up the whole thing myself, and it often seemed that I took two steps backward for every step forward. There were many times when I made a mistake that ruined another part, and I had to back up two or three steps to rebuild it.

But I finally put it all together and took it out for first light. I remember packing it into the car and driving it over to the reservoir, the big, concrete-topped water tank that my club uses for our star parties. I was so excited!

I set it up and started observing with it . . . and ran into one problem after another. I had used car wax on the ball, but that stuck like glue, except when it didn't, so the scope lurched around like a drunk. It actually creaked when I moved it. The balance was way off, so it wouldn't stay on target, and it wouldn't track except when it was pointed straight up (and did so poorly). The motor sounded like a B-52 taking off. The mount was wobbly as a Weeble. And at one point I tripped over one of the legs and scooted it sideways, somehow busting a couple square inches of one of the plywood plies completely off the leg. I was so disgusted with the whole works that I didn't even pick up the busted-off piece. I just hauled the scope back to the car and threw it in, not caring how badly I banged it up because I was planning to throw the whole $#@! thing away when I got home anyway.

I sat there in the car, fuming and close to tears at the same time, and one simple thought made it through the fog of emotion: "You're littering." By leaving the broken-off part out there on the reservoir deck, I was littering. So I went back and retrieved it. Drove home and unloaded the scope into the garage and went upstairs to bed. Didn't sleep much.

But over the course of the night, the chemicals in my bloodstream equilibrated again. I woke up in the morning feeling disappointed but no longer angry. I went out to the garage and looked at the mount. The damage was superficial; I could glue the plywood top layer back on, and the repair would hardly be visible. I could try a different wax. I could isolate the motor with rubber grommets. I could brace the wobbly legs. I started thinking of all the things I could do to make the scope work better, and slowly I regained my interest in the project.

It took weeks of tinkering to make it work. There were several days when I was convinced the whole design was lousy. Nobody else had done one of

▲ *Left:* The mount's original incarnation had the idler bearings angled wrong, wobbly legs, and a motor that sucked juice like a short circuit and sounded like a bomber taking off. *Right:* Braces between the legs and the platform stiffened up the mount, and a smaller motor solved the battery and noise problem. Note the angled idler bearings. This mount tracks like a dream!

ALL IMAGES COURTESY OF THE AUTHOR

these scopes,* and this was obviously why: They didn't work.

But I'd already put in over 100 hours on the mirror and probably another 100 on the scope, and when I was able to point it at something neat to look at, I did get a pretty good view through it. And it did sort of track. Not well, but better than nothing.

So, I kept tinkering with it, and I learned that the idler bearings were aimed in the wrong direction — a purely conceptual error that seemed so obvious I never doubted it until I was forced to — and I discovered ski wax, the perfect combination of low stiction and smooth glide. I found a smaller, quieter motor that pulled far less current and was much quieter than the first one. And slowly the concept came together.

One afternoon I was talking with an engineer friend whom I really respected, and he noticed the scope sitting in the entryway of my house. "What's that?" he asked. So I described it to him. And the look on his face was priceless. "You built that?" he asked. "From scratch?"

Yes, I did. And it worked, sort of. It was getting better and better every day, incrementally, as I addressed each problem in turn. And I realized at that moment that I was proud of that scope, proud as a new parent. Proud and eager to take it out under the night sky and use it.

It's still my favorite telescope 17 years later. Yet every now and then, usually as I'm putting it away after a long night out, I flash back to that night when I hauled it out of the car and banged it down next to my work-bench, wondering why I didn't just toss it directly into the garbage can on the other side of the wall.

The future sometimes hangs on such a fragile thread, it's amazing we ever get there. But get there we do. One step at a time.

■ Contributing Editor **JERRY OLTION** has almost given up on 15 telescopes.

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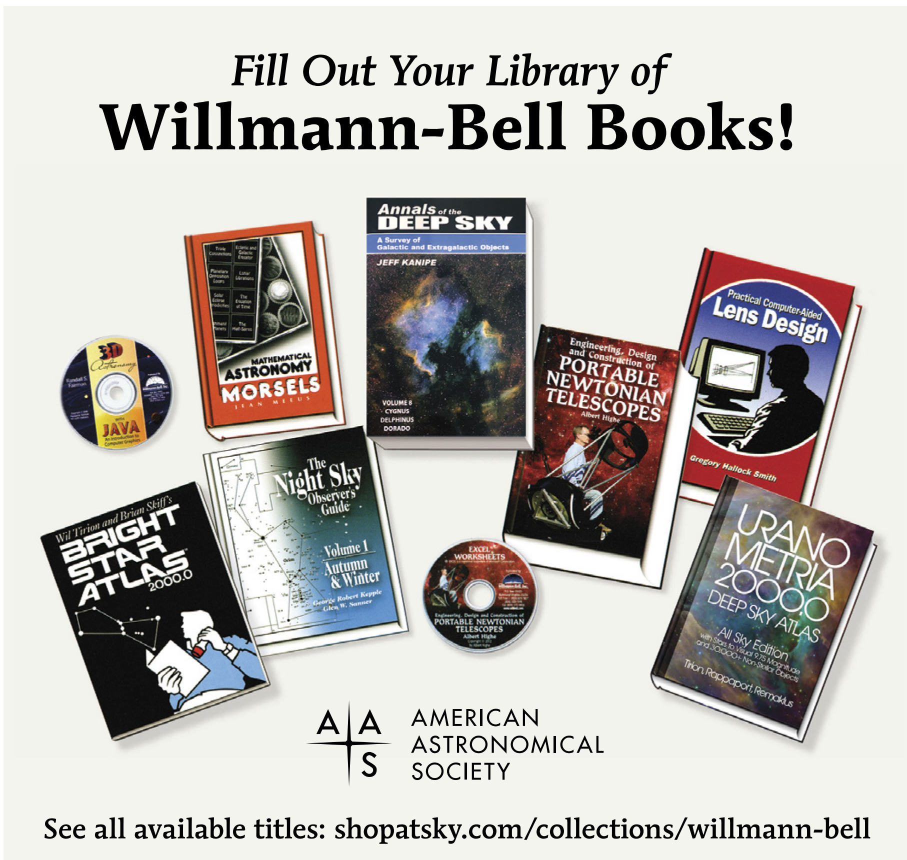
*I didn't yet know about Pierre Lemay, who had come up with the idea 10 years before me (*S&T:* Jan. 1996, p. 33).



Alberio, in the constellation Cygnus, the Swan, is perhaps the finest double star in the night sky.

What Is a Double Star?

A DOUBLE STAR is just like it sounds — two stars together in the sky. In most cases, you'll need a telescope or at least binoculars to tease them apart, but when you do you'll be amazed. Some with similar brightnesses resemble a pair of headlights coming at you from outer space. Others have a bright primary star whose light can all but overwhelm the light of its secondary star. Still other double stars are actually multiples, with three or more stars that may or may not be gravitationally bound to one another. And many double stars have distinct color signatures to them, as we'll see.

In short, double stars come in a bewildering variety of forms. They are a cornucopia of stellar jewels that offer unlimited observing opportunities for backyard stargazers. Indeed, after the Moon and planets, double stars are among the easiest objects to find and enjoy, even with small backyard telescopes. Sissy Haas, author of *Double Stars for Small Telescopes*, calls them "among the best-kept secrets in nature."

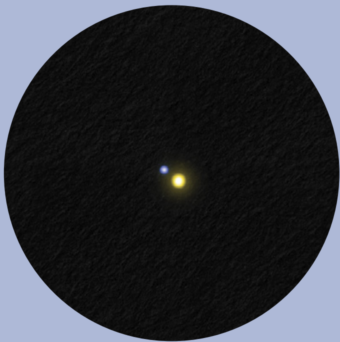
Seeing Double

A fun surprise for every beginner is the first time you look closely at a star you think is just a single star and find it to be a double. A good example is Mizar, the middle star in the handle of the Big Dipper, in Ursa Major. If you look closely with your unaided eye on a clear night, you'll see that the star is actually a pair: bright Mizar and slightly fainter Alcor. And if you observe the pair with a telescope, you realize it's actually a *multiple star*: Mizar has its own dimmer companion tucked up against it. In fact, Mizar and its close-in neighbor — officially known as Mizar A and Mizar B — are each also doubles, so Mizar is actually a quadruple-star system!

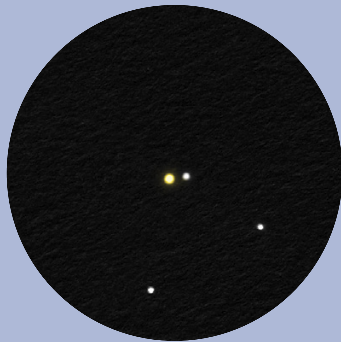
Mizar A and Mizar B comprise a true *binary star*. That means both stars likely formed out of the same spinning disk of gas and dust and are orbiting each other. Our Sun doesn't have a gravitationally bound companion, but the majority of stars in our galaxy do. Mizar and Alcor, on the other hand, are likely not an orbiting pair but just happen to be traveling together in space. They're probably an *optical double*, a double star in which the two suns might appear together but have no other relationship; in fact, one could be many thousands of light-years more distant than its "companion."

Some binary stars aren't resolvable in telescopes — backyard or otherwise — and were discovered by other means. An *eclipsing binary*, for example, is one

STEFAN BINNEWIES / JOSEF PÖPSEL / CAPELLA OBSERVATORY



Gamma (γ) Andromedae



Gamma (γ) Delphini

Eta (η) Cassiopeia

◀ Arizona observer Jeremy Perez made these sketches of double stars using a 6-inch Newtonian telescope. Notice the subtle color differences. North is up and east to left.

in which each of the two stars eclipses its mate once every orbit — which astronomers know only because we see them edge-on and the light of the primary dims periodically. In *spectroscopic binaries*, the two stars are so close together that they're not resolvable in any telescope. But using *spectroscopy*, or the study of their light, astronomers can sometimes tease apart stars that are visually not separable. This is how they determined, for instance, that Mizar is a four-star system.

Dabs of Color

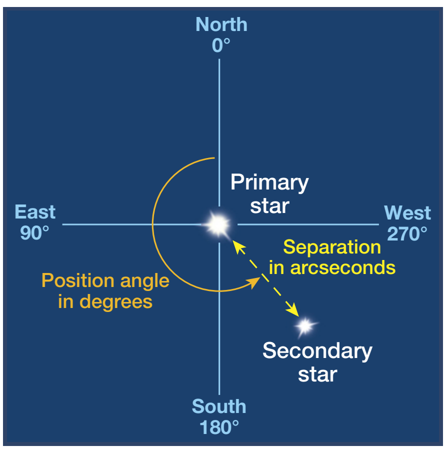
What many observers find most pleasing about double stars is their color contrasts. Take **Alberio**, for example, which is many observers' favorite double star. Also known as Beta (β) Cygni, Alberio sits at the bill-end of Cygnus, the Swan. Its bright orange primary and sapphire-blue secondary comprise arguably the most famous optical double in the sky.

Another standout is **Gamma Andromedae**, a binary in Andromeda. Known as Almach, the pair's striking golden and greenish-blue hues are obvious even in a small scope. (Like Mizar, Almach is also a quadruple-star system, with the primary and secondary each having its own orbiting star.)

Gamma Delphini, in Delphinus, the Dolphin, has a deep-yellow primary and a pale-green secondary. They are easily split in small telescopes. Haas has described the colors as "muted lemon and lime green."

Eta Cassiopeia has strikingly vivid tints. There's a distinctive brightness contrast as well, with four magnitudes difference between the primary and secondary. Many observers see the primary as deep yellow and the secondary as a reddish purple, which led *S&T* Contributing Editor Jim Mullaney, author of *Double and Multiple Stars and How to Observe Them*, to call Eta Cass the "Easter Egg double."

Note that colors are subjective: Different people often see different colors when viewing the same double star. When a double has a faint secondary, tints can also be entirely illusory, the effect of contrast with its much brighter primary. That's because, when two stars are close by each other, our brains naturally enhance any perceived color differences that may exist between them. In reality, the components of a double star have the same colors as single stars of the same type and temperature, which range from bluish-white to orange.



▲ Double stars are described by their *separation* in arcseconds and the *position angle* of the dimmer secondary with respect to the brighter primary. Position angle is measured from north around through east, south, and west, whatever the orientation of the eyepiece view.

Location, location

To describe double stars, astronomers use two measurements: *separation* and *position angle*. Separation of stars in a multi-star system is given in *arcseconds*. One arcsecond is 1/60th of an *arcminute*, which is 1/60th of a degree. As a guide, the Moon is about one-half of a degree in diameter. Double star enthusiasts delight in the challenge of splitting close pairs — especially those near the resolution limits of their telescopes.

Position angle, which tells you where to look for a secondary star in relation to the primary, is measured from north around through east, south, and west. This is true whatever the orientation of your eyepiece view, which can differ depending on your type of telescope (see *S&T:* Aug. 2023, p. 76).

Armed with these two numbers, experienced observers will not only know where to look for the often fainter secondary, but can also tell if they will be able to split that particular double. Note that because stars are continually in motion, these two figures can change significantly over time.

Thousands of Doubles

Want to dig deeper? Have a look at Haas's or Mullaney's books. To go all in, consult the definitive reference, the Washington Double Star Catalog, which lists over 100,000 double or multiple stars (**astro.gsu.edu/wds**). ■

DOUBLE STAR SKETCHES: JEREMY PEREZ / PEREZMEDIA.NET; CHART: *S&T* ILLUSTRATION

▷ DIAMOND DOWN UNDER

Tunç Tezel

The diamond-ring effect is seen seconds before totality during the April 20th solar eclipse. Several pinkish prominences and many bright coronal streamers, both typically seen during solar maximum, jut out along the lunar limb in every direction.

DETAILS: *Canon 6D camera with 100-to-400-mm lens. Total exposure: less than a second at f/8, ISO 400.*

▽ STELLAR LAGOON

Pavel Vorobiev

A bright blue bolide is reflected in Hanson Lagoon in Baja, California, as it streaked through Aries on July 23rd. A thunderstorm flashes along the horizon at right.

DETAILS: *Nikon D750 camera and Irix 15-mm lens. Stack of two 20-second exposures at f/2.4, ISO 800.*

ORION'S DUSTY HAIR

Dan Crowson

Cederbald 51 in northern Orion is a bluish reflection nebula that's surrounded by the larger emission nebula Sharpless 2-264. The bright star at bottom right is HK Orionis, a pre-main sequence binary star.

DETAILS: *32-inch Schulman Telescope with SBIG STX-16803 CCD camera. Total exposure: 18 hours through LRGB filters.*

◁ **TURNING BLUE**

Dan Llewellyn

After almost seven years of chilly winter under the shade of the planet's rings, heavy aerosols in the upper atmosphere of Saturn's southern hemisphere sunk, leaving behind lighter molecules that scatter blue light, turning the region blue. Two of Saturn's moons, Tethys (right) and Rhea (far right), circle just beyond its rings.

DETAILS: *Celestron C14 Schmidt-Cassegrain and Player One Mars-C II (IMX662) camera. Stack of 11,000 frames.*

▽ **FLASHING EQUINOX**

Chirag Upreti

As the Sun rose above the trees in New York City on the day of the 2023 vernal equinox, strong differential refraction in the atmosphere produced a rare morning green flash.

DETAILS: *Sony α7R III camera and 150-to-600-mm lens. Total exposure: 1⁄4,000 second at f/18, ISO 64.*

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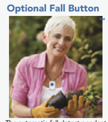

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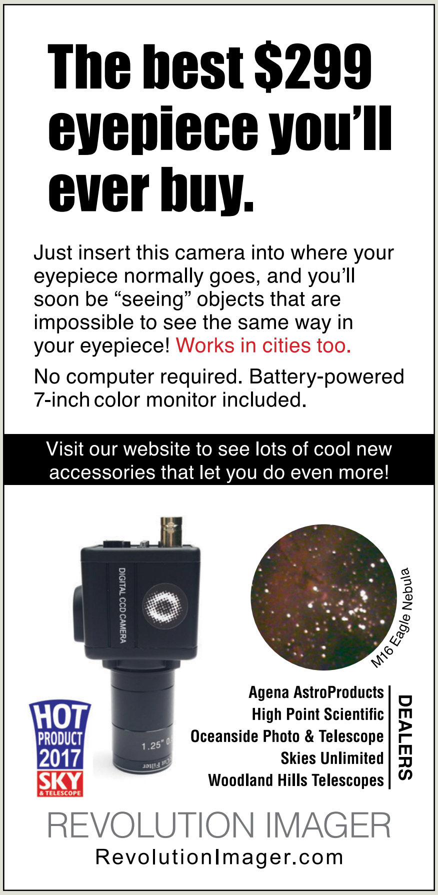

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Event Calendar

Here's the info you'll need to "save the date" for some of the top astronomical events in the coming months.

M. QUINN / NPS

September 14–17
GREAT LAKES STAR GAZE
Gladwin, MI
greatlakesstargaze.com

September 15–16
HIDDEN HOLLOW STAR PARTY
Bellville, OH
wro.org/hidden-hollow-star-party

September 15–17
BLACK FOREST STAR PARTY
Cherry Springs State Park, PA
bfsp.org

September 22
ASTRONOMY DAY
Everywhere
astroleague.org/astronomy-day

September 22–23
ASTRONOMY AT THE BEACH
Brighton, MI
https://is.gd/AstroAtBeach23

September 29–30
ASTROASSEMBLY
North Scituate, RI
https://is.gd/astroassembly23

October 7
NOVAC STAR GAZE
C.M. Crockett Park, VA
https://is.gd/NOVACStarGaze23

October 7–15
PENNYRILE STARGAZE
Dawson Springs, KY
facebook.com/southstarparty

October 8–15
PEACH STATE STAR GAZE
Deerlick Astronomy Village, GA
atlantaastronomy.org/pssg

October 9–14
ELDORADO STAR PARTY
Eldorado, TX
eldoradostarparty.org

October 12–15
ILLINOIS DARK SKIES STAR PARTY
Chandlerville, IL
sas-sky.org

October 13–22
JASPER DARK SKY FESTIVAL
Jasper National Park, Alberta
jasperdarksky.travel

October 15–20
ENCHANTED SKIES STAR PARTY
Pie Town, NM
enchantedskies.org

October 19–22
SJAC FALL STAR PARTY
Belleplain State Forest, NJ
sjac.us/star-party

November 7–12
DEEP SOUTH STAR GAZE
McComb, MS
dssg.boards.net/post/950

November 10–17
CHIEFLAND ASTROFEST
Chiefland Astronomy Village, FL
chieflandastro.com/astrofest

- For a more complete listing, visit https://is.gd/star_parties.

Sic Transit Mercurius Gloriosus

To catch Mercury's most recent transit, the author and his wife had to bolt for the hills.

THE MORNING OF November 11, 2019, dawned dim and fuzzy, hidden behind a thick layer of valley fog. That's a normal sight in Oregon's Willamette Valley, but November 11th was no normal morning. It was the day of Mercury's transit of the Sun, and the last chance my wife Kathy and I would likely have in our lifetimes to witness such a spectacle.

My astronomy club, the Eugene Astronomical Society, had planned a star-and-planet party to share the event with the public through solar-filtered scopes, but that was clearly off. So Kathy and I piled into our car full of astro gear and drove for high ground.

Our Plan-B site just out of town, at an elevation of about 600 feet above the valley floor, was fogged in even thicker than our home. That left Plan C: a lengthy drive out of town for some serious altitude. We sped toward our club's highest observing site on the flanks of the Cascades' Mount June, knowing that the Sun was nearly up and Mercury was already in mid-transit.

On the way, we discussed our folly. Why do amateur astronomers live in the Pacific Northwest? We went through this very same thing on the day of the 2017 total solar eclipse. Then we also had fog and a frantic drive all the way over the mountain range before we broke free of it. We saw the eclipse, but it was a nail biter all the way. Why didn't we move to Arizona after that?

Fortunately, history repeated itself. Just two miles up the winding mountain road to the top, we broke out of the fog. Bonus: We did it at a wide spot in the road, with a good east/southeast view. The Sun was still behind a ridgeline, but we could see from the bright glow that it was about to crest the rise. So we set up our scopes and waited for our chance. The fog was right at our feet, but overhead it was crystal-clear.

The Sun rose. In our scopes, it was rippling madly in the morning turbulence above the trees, but we could just make out the tiny black smudge of Mercury. Between glimpses, I wildly texted and emailed our club: "Come on up!"

People started arriving just a few minutes later. The first had settled on the same Plan C we had; others saw my posts and jumped in their cars and headed up the mountain. One club member brought his seven-year-old daughter and three-year-old son so they could witness the first of what he hoped would be a lifetime of similar astronomical events. The party atmosphere grew from excited to giddy as the Sun rose higher into steadier air and we could see the sharp, jet-black silhouette of our solar system's innermost planet in motion.

▲ The author's observing site for the 2019 Mercury transit was just above the cloudtops in this view from a ridgeline high up on Oregon's Mount June.

BILL MURRAY

As the transit drew to a close, our line of observers cycled past the eyepieces faster and faster so everyone could see every stage. Then, right before my eyes, Mercury slipped away. The transit was over. The next one visible from here won't be until 2049, and I'm already 66 (as I write this in 2023), so I'm unlikely to see another.

It wasn't a somber moment, though. It was a glorious, triumphant moment! We had faced adversity, but we had literally driven the extra mile and succeeded in viewing the transit in the foggy Pacific Northwest. The sense of accomplishment was far greater than if we had simply set up our telescopes in the driveway and watched it.

And that, in a nutshell, is why we continue to live where we do. The challenge is sometimes frustrating, but the reward when you meet it head-on and succeed is sublime.

■ **JERRY OLTION** has seen two Mercury transits and one Venus transit despite living in the Pacific Northwet.


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The image on the right is the famous Pillars of Creation (M16) taken with the Wide Field Planetary Camera of the Hubble Space Telescope. The image on the left is taken with a QHY600M-PH Camera through a 7-inch refractor from the author's backyard in Buenos Aires. Courtesy Ignacio Diaz Bobillo. To see the original composition, resolution and acquisition details, visit the author's Astrobin gallery at https://www.astrobin.com/users/ignacio_db/

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